PHARMACIA

Pharmacia Groningen BV
Van Swietenlaan 5
9728 NX GRONINGEN
The Netherlands

Phone Nr.: + 31 50 5296600
Fax Nr.: + 31 50 5267860

REPORT

TITLE: Bifocal foldable lens design based on corneal wavefront aberration

DATE: [redacted]

REPORT#: Rp2691r

AUTHOR:	FUNCTION:	SIGNATURE:	DATE:
Henk Weeber	Research Scientist Biophysics		[redacted]
APPROVED:	FUNCTION:	SIGNATURE:	DATE:
Marrie v.d. Mooren	Sr. Development Engineer		[redacted]
APPROVED:	FUNCTION:	SIGNATURE:	DATE:
Thom Terwee	Manager Biophysics Department		[redacted]

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John Kappelhof
Sverker Norrby

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1. EXECUTIVE SUMMARY

With Tecnis model Z9000, a lens is designed which corrects the corneal spherical aberration. The lens has an aspherical anterior surface, which induces a negative spherical aberration, equal but opposite to the average corneal spherical aberration of a cataract population. The resulting design has improved optical performance, especially for larger apertures[1,2].

The design principle of Tecnis model Z9000 is applied on a bifocal silicone HRI lens. The principle bifocal specifications were copied from CeeOn model 811E: The design has a +4D reading add and a 50:50% light distribution between near and far vision. These specifications are met using a diffractive profile on the posterior lens surface.

For the posterior surface, the diameters of the rings are identical to CeeOn model 811E. The stepheight of the rings is 2.32 micrometer (model 811E: 1.85 micrometer).
Similar to Tecnis model Z9000, the anterior surface is used for the correction of spherical aberration. Two alternatives were evaluated:

1. an optimized anterior surface, which minimized the spherical aberration for near and far vision
2. an anterior surface identical to Tecnis model Z9000

The theoretical performance as well as measurements on prototype lenses revealed that there is no significant difference in performance between these two alternatives.

Conclusions:

1. A bifocal foldable diffractive design with a regular Tecnis Z9000 anterior surface corrects for spherical aberration.
2. Compared to CeeOn model 811E, the resulting design shows approximately a factor 3 improvement of optical quality (MTF) for a 5mm pupil. For a 3mm pupil, the improvement is insignificant.

2. INTRODUCTION

With model Z9000, a lens is designed which corrects the corneal spherical aberration. The lens has an aspherical anterior surface, which induces a negative spherical aberration, equal but opposite to the average corneal spherical aberration of a cataract population. The resulting design has improved optical performance, especially for larger apertures[1,2].
The design principle of model Z9000 can also be applied for bifocal lenses. Pharmacia has a PMMA bifocal lens, model 811E, which is a diffractive lens with a +4D power add for reading. This design can be transferred to HRI material[3]. Bifocal lenses have 2 foci. This means that one object will generate two images. In the ideal situation, one of the two images will be focused on the retina. While the other image is out of focus, it will still cause some blurr on the retina, which decreases the optical quality. Therefore, by their nature, the optical quality of bifocal lenses is lower than monofocal lenses of the same design.
This report shows how the design methods of model Z9000 are applied on a bifocal foldable lens. All files that were used to compile this report, including measurement data, calculation results and OSLO CCL programs, are stored on a CD-ROM as appendix 8 of this report.

3. METHODS

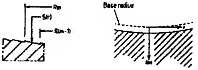
The design is based on the diffractive bifocal design of model 811E. This means that the same equations for the surface profile are used for the posterior surface, however with different parameters[3](figure 1). Similar to model Z9000, the anterior surface is made aspherical[4].
Using these principles, the optical design of bifocal lenses comprises the determination of 3 items:

1. secure the light distribution between the 2 foci
2. secure the correct power add for near vision
3. secure the correct base power

With the new design, an additional item is added:

4. secure a specific spherical aberration

As for model 811E, the target light distribution between near and far focus is 50%:50% and the target power add for near vision is 4 diopters.



Sag equation according model 811E:

$$S(r) = -R_b + \sqrt{R_b^2 - r^2} + k * P_m(r) - S_1 \qquad (1)$$

r = distance from the optical axis
R_b = radius of posterior lens surface
k = constant, influencing the stepheight of the diffractive profile
S_1 = constant correcting the central thickness of the lens (was not present in original 811E equation)
S_1 is introduced in order to secure the condition S(0)=0.

$$P_m(r) = P_0 - a * \sqrt{1 + \frac{r^2}{b^2}} \qquad (2)$$

$$P_0 = \frac{40 + 0.00046 * m}{0.246} \qquad (3)$$

$$a = \frac{40 - 0.000412 * m}{0.246} \qquad (4)$$

$$b^2 = 0.246 * a^2 \qquad (5)$$

$$S_1 = \frac{0.000872}{0.246} * k \qquad (6)$$

$$R_i = R_1 * \sqrt{m} \qquad (7)$$

$$m = 1,2,3... \qquad (8)$$

Pm(r) = description of the diffractive profile
R_i = radius of the rings
R_1 = radius of the first diffractive ring
m = ring number

Figure 1. Equations describing the diffractive profile.

3.1. Design methods

The calculation methods which are used for determining the theoretical performance are described in detail in the report Rp2681r[5].

3.1.1. Design cornea

The design cornea is desribed in report 2278. This design cornea is a 1-surface model. The refractive index of the cornea is the keratometry index of 1.3375. However, for diffractive lenses it is essential to use the real in vivo refractive index on the posterior (diffractive) lens surface. Therefore, a 2-surface model is used which has the same characteristics of the 1-surface model.

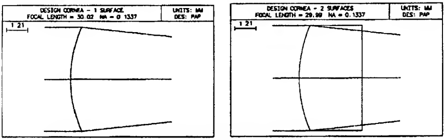


Figure 2. 1-surface (left) and 2-surface (right) design cornea.

The 2-surface cornea was constructed from the 1-surface cornea by adding a flat transition (surface) between the cornea and an aqueous/vitreous at 3.6mm from the cornea apex. The spherical aberration of the eye is remained within 0.03% of the original 1-surface cornea (see appendix 1).

3.1.2. Light distribution

The light distribution of the diffractive bifocal lens is determined by the stepheight of the diffractive zones.
The theoretical stepheight for a 50:50% light distribution is 2.25 μm[5]. This theoretical value is challenged and fine-tuned by means of prototype testing. It has to be noted that the light distribution is now defined in the Z9000 eye model (design cornea), while for model 811E, the light distribution was defined in the Gullstrand eye model.

3.1.3. Power add for near vision

The power add is determined by the diameters of the diffractive zones. Theoretically, this is independent of the refractive indices of the lens and the surrounding medium. Therefore, the same zone diameters are used as for model 811E.

3.1.4. Base power

The lens power of a normal monofocal lens is defined by the paraxial focus in situ[6,7]. Diffractive bifocal lenses do not have a theoretical paraxial focus. Therefore, an alternative approach was used for model 811E[8]. This approach basically means that, comparing a bifocal

and monofocal lens of the same lens power, the best focus should be located at the same position when the lens is measured in situ. This makes the practical behavior of monofocal and bifocal lens powers comparable.

In the design phase of the lens, an estimate can be generated by giving the diffractive lens a base radius comparable to the radius of a monofocal design. Fine-tuning is done in a later stage, when prototype lenses are measured.

3.1.5. Optical quality

The optical quality of diffractive bifocal lenses can be estimated using the optical design program OSLO[9].
The methods are described in detail in report Rp2681r[5].

3.1.6. Optimization of optical quality

The anterior surface of the bifocal lens can be optimized in order to reduce the overall spherical aberration, equivalent to what was done for model Z9000[1]. Alternatively, the exact Z9000 anterior surface can be applied onto the bifocal lens.
Optimization of the anterior surface is performed on the symmetrical Zernike terms:

OSLO Zernike term	weight factor
Z8	1
Z15	0.1
Z24	0.01

The optimization is performed for far and near vision simultaneously. For the calculations in OSLO, it means that for each optimization step, the vector sum of the Zernike term for near vision and far vision is taken as the operand (appendix 2). A real near vision configuration was generated by putting the light source in a position close to the eye.
As a starting point, the model Z9000 conic constant is used and *ad*=*ae*=0. The polynomial terms *ad* and *ae* are used for optimization.

3.2. Measurement methods

3.2.1. Z9000 eye model

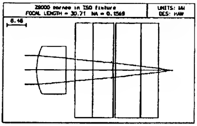


Figure 3. Z9000 cornea in front of the ISO wet cell.

For the measurement of the optical modulation transfer function (MTF), a new cornea was used, which fits in front of a wet cell. The wet cell is identical to the ISO wet cell. The new PMMA cornea generates a wavefront that is identical to the wavefront of the design cornea. The focal point is in air, which facilitates automated focussing on the Eros Ealing optical bench. The design of the cornea is described in appendix 3. The refractive index of PMMA is measured from the actual PMMA rod. The refractive index of water is adjusted to match with the silicone HRI material: For diffractive lenses, the difference between the refractive index of the lens and the medium (aqueous or water) is important for the light distribution of the lens. Therefore, water with a refractive index of 1.3406 has to be used (Appendix 6). The refractive index of the water is changed by adding poly-ethyleenglycol (PEG200).
The advantages of the eye model over the previous one (report 2236) are:

- the PMMA cornea is not in direct contact to the medium (water), which makes it easier to maintain.
- The focus position is in air, so that the automated focusing of the Ealing optical bench can be used.

3.2.2. Light distribution

The light distribution is measured in the Z9000 eye model. At each focal point, the line-spread-function is measured. The central four pixel intensities are used as a measure of the amount of light in each focus.

3.2.3. Power

The power of the bifocal lens is determined by measuring the back focal length (BFL) in the waterbath. The conversion of BFL to lens power is based on the following definition of bifocal lens power[8]:

> The bifocal power of the lens is calculated from the back focal length in best focus condition, in the same way as is done for the paraxial lens power of a monofocal lens with equal geometry (radii and central thickness).
> Calculation to be performed under the conditions:
> 1. The spherical aberration is presumed not to be influenced by diffractive pattern.
> 2. The location of the second principle plane is presumed not to be influenced by the diffractive pattern and is the same for both focal points.
>
> Measurement of best focus to be determined under the conditions:

1. Collimated light (wavelength 550 nm) reaches the lens.
2. There is a 3mm aperture in front of the lens.
3. Best focus is defined as the position with the highest MTF-value at a spatial frequency of 50c/mm.

There is one difference with the original definition which was used for model 811E: For the new model, the spherical aberration depends on the lens power, and therefore on the focal point that is measured. In practice it means that for the far- and near focus different values for the spherical aberration have to be used. The background is that the spherical aberration of the current lens is much higher (when measured in a waterbath) than a spherical lens, while the amount of spherical aberration is also highly power-dependent. For model 811E, this diopter dependency was negligible.
The add power is defined as the difference between the powers of the near focus and far focus.
The measurement procedure is described in appendix 4.

3.2.4. Optical quality

The MTF is measured in the Z9000 eye model. Focussing is performed at 25c/mm, which is according to the current draft standards for multifocal lenses. The lenses are measured with apertures of 3 and 5 mm diameter. At 5mm aperture, the lens is measured at 3 positions, 45 degree apart, in order to account for any astigmatism.

4. RESULTS

4.1. Prototype designs

The prototype designs consist of an anterior and posterior optical surface. The posterior surface is the diffractive surface, according the equation also used for model 811E. The parameters k and R_1 (equations 1 and 7 in figure 1), defining stepheight and the ring-diameters, have to be adapted for the silicone HRI design. Theoretically, the ring diameters for a given power add are independent of the material used, so the value used for model 811E is taken (R_1=0.513mm).
The k-value determines the light distribution. In order to verify the k-value, a separate test series was made and tested (appendix 5). This test indicated that a k-value of 0.6536 results in a 50:50 light distribution. The corresponding stepheight of the rings is 2.32 micrometer.

The anterior surface was optimized for the symmetrical Zernike terms in far and near vision. The optimization has been performed for lens powers 15.0, 20.0 and 26.0D. On average, the resulting spherical aberration (OSLO Zernike Z8) is reduced with a factor 100. The resulting Zernike coefficients are listed in figure 4, the lens geometry in figure 5.

		FAR			NEAR		
Power	Anterior surface	Z8	Z15	Z24	Z8	Z15	Z24
15D	Optimized	-0.04	-0.11	-0.02	0.02	-0.10	-0.02
	Z9000	-0.07	0.01	-0.02	-0.01	0.01	-0.02
	Spherical	1.41	0.03	-0.02	1.46	0.03	-0.02
20D	Optimized	-0.03	-0.12	-0.02	0.02	-0.11	-0.02
	Z9000	-0.08	0.00	-0.02	-0.04	0.01	-0.02
	Spherical	1.66	0.04	-0.02	1.70	0.04	-0.02
26D	Optimized	-0.02	-0.12	-0.03	0.01	-0.12	-0.02
	Z9000	-0.09	0.00	-0.02	-0.06	0.01	-0.02
	Spherical	2.12	0.06	-0.02	2.16	0.06	-0.02

Figure 4. Theoretical performance of the prototype design, in terms of the symmetric Zernike coefficients. The Zernike coefficients are expressed in wavelengths. They are calculated in OSLO, in the design eye model, with a rectangular spot diagram in image space with using over 200.000 rays. For near vision, the reading distance is 40cm. For far vision, the aperture at the cornea is 6mm in diameter, which corresponds with an aperture diameter of 5.1mm at the lens position. For near vision, the entrance beam radius is adapted: The pupil size at the IOL location is the same for far and near vision.

	15D	20D	26D	
Anterior surface				
Radius	16.225	12.154	8.333	mm
Conic constant	-0.98656	-1.01855	-1.05018	[-]
AD	-4.3209E-04	-4.9285E-04	-6.0581E-04	mm^{-3}
AE	-4.2491E-05	-4.8990E-05	-5.9954E-05	mm^{-4}
Posterior surface				
Geometric radius*	(-16.225)	(-12.154)	(-8.333)	mm
Base radius R_0	-17.082	-12.586	-9.547	mm
Ring radius R_1	0.513	0.513	0.513	mm
k-value	0.6536	0.6536	0.6536	mm
stepheight	2.32	2.32	2.32	µm
Central thickness	1.03	1.13	1.24	mm

Figure 5. Lens geometry of the prototype lenses*. The geometric radius is added to indicate the overall geometry of the lens as if the posterior radius is a normal spherical surface, in this case equi-biconvex.

4.2. Theoretical performance of the prototype designs

In the previous paragraph, the theoretical performance of the prototype designs was described in terms of the symmetrical Zernike coefficients. Figure 4 shows that the optimised design results in the smallest spherical aberration (Z8). Also the design with the original Z9000 shows very small values for the spherical aberration, though a little higher than the optimised design.

The modulation transfer function can be evaluated of the prototype designs, compared with a spherical diffractive design and with a spherical monofocal lens design. (figure 6, 7).

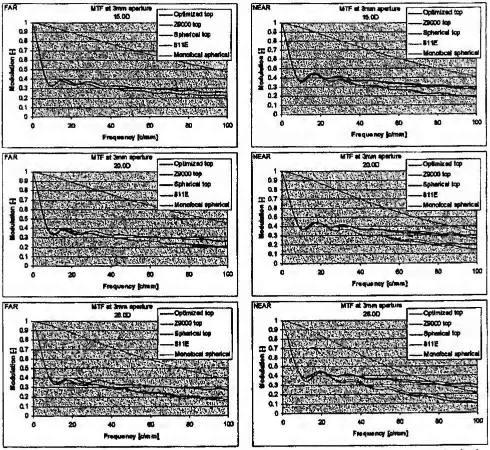


Figure 6. modulation transfer function of the prototype designs, compared with a spherical diffractive design and with a spherical monofocal lens design at 3mm.

The figures 6 and 7 show that the gain of the aspherical surface is there for the 5mm aperture, where the bifocal lens shows a contrast even higher than a spherical monofocal lens. Furthermore, the optimised anterior surface shows comparable MTF to the Z9000 anterior surface. For the very high frequencies at near vision the Z9000 surface is even slightly better.

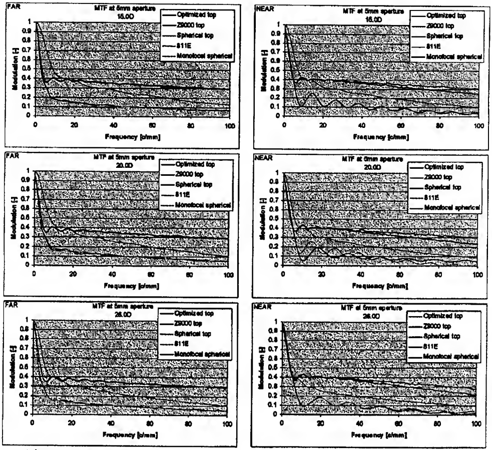


Figure 7. modulation transfer function of the prototype designs, compared with a spherical diffractive design and with a spherical monofocal lens design at 5mm. The heavy fluctuations of the MTF for the spherical top bifocal and 811E do not represent phase reversals of the phase transfer function. There is one phase reversal: model 811E, 20.0D, near vision, at 95c/mm (modulation = 0). Apart from this, the phase is always close to zero (<1°).

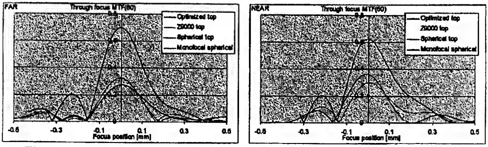


Figure 8. Through focus MTF at 50c/mm for 20.0D lenses and a 3mm aperture.

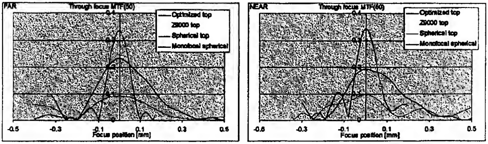


Figure 9. Through focus MTF at 50c/mm for 20.0D lenses and a 5mm aperture.

4.3. Measurement of prototype lenses

The lenses are measured on their optical performance, in an eye model and in a waterbath. Shape measurements on diffractive and aspherical surfaces are extremely difficult, especially on a flexible and sticky silicone surface. Feasibility measurements were carried out with optical and mechanical measuring techniques with varying success. The results were not reliable enough for extensive reporting here. Nevertheless all results showed that the lenses were close to the design in the sub-micron range (average deviation of stepheight 0.04 micrometer). Also mechanical tests on the molds (Talysurf) indicated a good result. Furthermore, the shape of the lenses was secured by using production procedures standard for regular Z9000 lenses. The test lenses were not angle set and not sterilized.

4.3.1. Eye model

The lenses were measured in the new Z9000 eye model as described in appendix 3. The water/PEG200 solution with a refractive index of 1.3406 was made and measured in the AR chemical lab (appendix 6).
The Z9000 PMMA cornea in front of the ISO wet cell is qualified by through focus and through frequency MTF measurements at 3mm and 5mm pupil. The measurement results are displayed in figure 10, together with the theoretical curves. Focussing was performed at 50c/mm. The measured graphs compare well with the calculated graphs. As a check, a Z9000 lens was measured as well (figure 11).

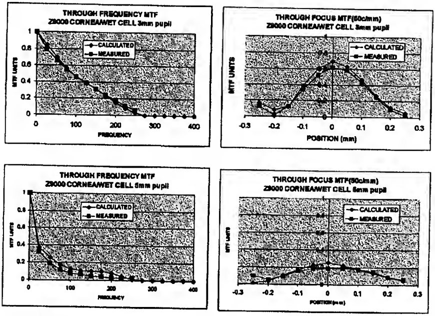


Figure 10. Measured through frequency and through focus MTF curves for the new Z9000 cornea for the wet cell, both for a 3mm and 5mm aperture.

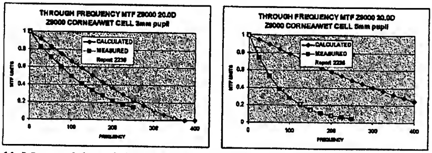


Figure 11. Measured through frequency MTF curves for a Z9000 lens, 20.0D, in the eye model. As a reference, the measured data from the lens verification report 2236 is added.

4.3.2. Modulation Transfer Function

Lenses were measured in the eye model on the optical bench. The measuring conditions were:

- Refractive index of the water (+PEG200) 1.3406
- Automatic focussing on MTF at 25c/mm
- Maximum analysis window of the linear photodiode array, leaving $^{1}/_{16}$ unused at the edges.
- For 3mm apertures, 1 measurement per focal point was made, for 5mm apertures, 3 measurements per focal point were made (lens at –45°, 0° and +45°)
- 8 lenses per prototype, per lens power

The results are given in figures 12. The results show that the optimized top and the Z9000 top have comparable performance in terms of MTF. At a 5mm aperture they are much better than model 811E.

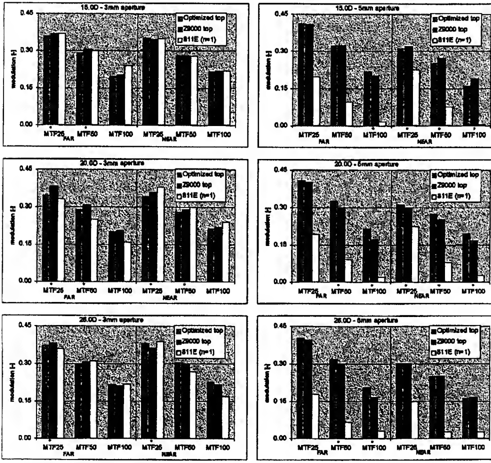


Figure 12. Modulation transfer values for 25, 50 and 100c/mm and aperture 3mm. The data of the optimized top and the Z9000 top is the average of 8 lenses. The data of model 811E is based on the measurement of one lens per diopter.

The results show that the optimized top and the Z9000 top have comparable performance in terms of MTF. At a 5mm aperture they are much better than model 811E. The standard deviation of every series of 8 lenses was small, with a standard deviation less than 0.02 MTF units (3mm and 5mm aperture). For the 5mm aperture, 3 measurements were performed per focal point, while the lens was rotated 45 degrees in between the measurements. The variation between these 3 measurements on the same lens depends on the spatial frequency and was 0.01, 0.02 and 0.03 MTF units (s.d.) for 25, 50 and 100c/mm respectively.
Figure 13 shows the ratio between the measured MTF and the theoretical MTF for the prototype with the Z9000 top. The theoretical MTF was calculated for lens under MO-lab conditions. The average ratio of the 3 spatial frequencies for the 3mm pupil is 88%, with a minimum of 71%. This is just within the ISO standard for monofocal lenses, which states that the lens optical quality should be greater or equal than 70% of the theoretical performance.

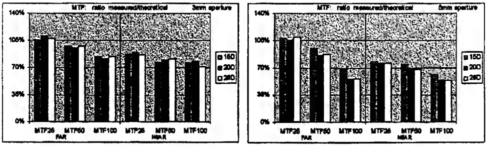


Figure 13. Ratio of measured/calculated MTF for prototype with Z9000 top.

4.3.3. Light distribution

The light distribution was calculated from the signal on the diode array, obtained during the MTF measurements for a 3mm aperture. The light distribution is defined as the ratio between the far and near focus. Figure 14 shows only the amount going to the far focus. The data shows no relationship between light distribution and lens power.

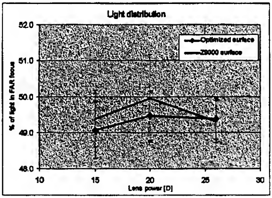


Figure 14. Light distribution: Amount of light that reaches the far focus. The error bars correspond with plus and minus one standard deviation.

4.3.4. Lens power

The lens power was determined by measuring 8 lenses per diopter. Only the prototype with the Z9000 top has been measured. The add power is very well on the target of 4 diopter. The base power (far) is a little off and needs fine-tuning.

Nominal	Measured lens power			Deviation	
power	FAR	NEAR	ADD	FAR	ADD
15.0	14.55	18.53	3.98	-0.45	-0.02
20.0	19.66	23.71	4.05	-0.34	0.05
26.0	25.78	29.75	3.97	-0.22	-0.03

Nominal	Standard deviations [D]		
power	FAR	NEAR	ADD
15.0	0.08	0.14	0.15
20.0	0.11	0.04	0.10
26.0	0.05	0.06	0.03

Figure 15. Measured lens power and standard deviations.

4.3.5. Lens power fine-tuning

Based on the measurement results, the lens power needs fine-tuning. The method used here, is to compare the measured result with a calculated paraxial lens power, based on the design anterior radius, the design central thickness and the design base posterior radius R_b (equation 1, figure 1). This leads to the following deviation of lens powers:

	design values						
Nominal Power	Anterior radius	Posterior base radius Rb	Central Thickness	TLE* Power	Measured power	deviation	proposed correction
15.0	16.225	-17.082	1.03	14.62	14.55	-0.07	0.07
20.0	12.154	-12.586	1.13	19.66	19.66	0.00	0.00
26.0	9.333	-9.547	1.24	25.71	25.78	0.07	-0.07

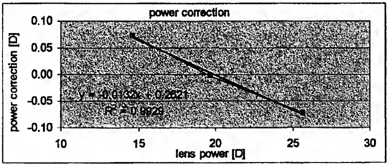


Figure 16. Lens power correction of the prototype with Z9000 top.
* TLE = thick-lens-equation, using the design geometry as input data.

The lens power correction is applied on the base radius Rb. The resulting lens data are:

	Anterior surface identical to Z9000				Posterior surface k=0.6536 R1=0.513	
		Aspherical terms:				
Lens Power	Radius	CC	AD	AE	Base radius Rb	Central Thickness
15.0	16.225	-0.988562	-8.03E-04	-7.23E-06	-16.087	1.03
15.5	15.699	-0.985816	-8.12E-04	-7.57E-06	-15.583	1.04
16.0	15.207	-0.99036	-8.21E-04	-7.93E-06	-15.110	1.05
16.5	14.745	-0.99753	-8.29E-04	-8.30E-06	-14.665	1.06
17.0	14.309	-0.99846	-8.39E-04	-8.69E-06	-14.245	1.07
17.5	13.899	-1.00088	-8.48E-04	-9.09E-06	-13.848	1.08
18.0	13.511	-1.00077	-8.58E-04	-9.52E-06	-13.473	1.09
18.5	13.144	-1.00030	-8.68E-04	-9.96E-06	-13.117	1.10
19.0	12.797	-1.00744	-8.78E-04	-1.04E-05	-12.780	1.11
19.5	12.467	-1.00314	-8.89E-04	-1.09E-05	-12.459	1.12
20.0	12.154	-1.018548	-8.99E-04	-1.14E-05	-12.154	1.13
20.5	11.856	-1.023293	-9.10E-04	-1.19E-05	-11.864	1.13
21.0	11.572	-1.027614	-9.21E-04	-1.25E-05	-11.587	1.14
21.5	11.301	-1.030542	-9.33E-04	-1.31E-05	-11.322	1.15
22.0	11.043	-1.036125	-9.44E-04	-1.37E-05	-11.069	1.16
22.5	10.796	-1.034876	-9.57E-04	-1.43E-05	-10.828	1.17
23.0	10.560	-1.037706	-9.69E-04	-1.50E-05	-10.596	1.18
23.5	10.334	-1.039948	-9.81E-04	-1.56E-05	-10.374	1.19
24.0	10.117	-1.041622	-9.94E-04	-1.63E-05	-10.161	1.20
24.5	9.909	-1.043677	-1.01E-03	-1.71E-05	-9.957	1.21
25.0	9.709	-1.046434	-1.02E-03	-1.79E-05	-9.760	1.22
25.5	9.517	-1.048667	-1.04E-03	-1.87E-05	-9.572	1.23
26.0	9.333	-1.050179	-1.05E-03	-1.95E-05	-9.390	1.24

Figure 17. Lens optical design of the bifocal foldable lens with an anterior surface profile which is identical to Tecnis model Z9000.

5. DISCUSSION

This report has shown that the Tecnis Z9000 design principles can be successfully applied on bifocal lenses. Two approaches were used: one using the proven Z9000 anterior lens shape combined with a diffractive posterior surface. Alternatively a new anterior lens shape was generated by optimizing the wavefront aberrations for the far as well as the near focus. The performance of these two types of lenses, in terms of MTF, showed to be identical, in theory as well as according the measurement of prototype lenses.

The improvement of the ZM001, compared to model 811E, is significant. However this is only true for the larger pupils (larger than 3mm). For a 5mm aperture, the MTF of the new bifocal design is even better than a spherical monofocal lens. Caution has to be taken to

translate this to clinical behavior, since the clinical behavior is also influenced by:
- perception of the out-of-focus image
- scatter

The theoretical through focus behavior (figures 8 and 9) indicates that the depth of focus is somewhat reduced for the larger pupil sizes. However, compared to the monofocal Z9000 model there doesn't seem to much difference[2]. Through focus measurements of prototype lenses can give more insight in the through focus behavior. It should also be noted that the theoretical calculations of MTF of diffractive multifocal lenses have to be interpreted with caution. The calculation routines of out-of-focus MTF have not been verified. For similar reasons, no calculations have been performed with tilts and decentrations.

Currently, there are no approved standards for the optical performance of multifocal standards. For model 811E, Pharmacia has generated its own specification, based on measurement in the Gullstrand eye model. A similar approach could be performed with the new model, based on the Z9000 eye model. For the 3mm aperture, the measured MTF is more than 70% of its predicted behavior. In this respect it fulfils the ISO standard for monofocal lenses. Whether this is an appropriate specification would need to be further verification, since there is currently not much room left (71% at 26D). Deviation from this standard can be justified by:

1. The standard is for monofocal lenses, not bifocal lenses
2. Prediction of diffractive bifocal lenses is difficult, with limited accuracy
3. The Z9000 eye model has an aspherical surface, creating an additional measurement error

6. REFERENCES:

1. P. Piers, 'Z11 design based on corneal wavefront aberration', PG report R2278.
2. M. van der Mooren, 'CeeOn 911Z verification report', PG report Rp2236r.
3. H. Weeber, 'Feasibility report bifocal silicone IOL', PG report 1727.
4. H. Weeber, 'Influence of the position of the aspheric surface on optical quality', PG report Rp2524r
5. H. Weeber, 'Design tools for diffractive bifocal lenses', PG report Rp2681r.
6. ISO standard: ISO11979-1
7. ANSI standard: ANSI Z80.7-1994
8. J. Hermans, 'Bifocal lens power: Definition and practical implementation', PG report 1031.
9. OSLO Premium Edition Revision 6.1. Lambda Research Corporation, Littleton, MA

Appendix 1: Design cornea

*LENS DATA

DESIGN CORNEA - 1 SURFACE

SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPE	NOTE
OBJ	--	1.0000e+20	1.0000e+14	AIR		
1	7.575000	3.600000	3.000003 S	KERATOM	M	*
AST	--	--	2.640233 AS	KERATOM	P	
3	--	0.900000	2.640233 S	KERATOM	P	
4	--	25.519444 S	2.550292 S	KERATOM	P	
IMS	--	--	2.2444e-05 S			

*CONIC AND POLYNOMIAL ASPHERIC DATA

SRF	CC	AD	AE	AF	AG
1	-0.141350	--	--	--	--

*REFRACTIVE INDICES

SRF	GLASS	RN1	RN2	RN3	VNBR	TCE
0	AIR	1.000000	1.000000	1.000000	--	--
1	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
2	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
3	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
4	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
5	IMAGE SURFACE					

*WAVELENGTHS

CURRENT	WV1/WW1	WV2/WW2	WV3/WW3
1	0.587560	0.486130	0.656270
	1.000000	1.000000	1.000000

*LENS DATA

DESIGN CORNEA - 2 SURFACES

SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPE	NOTE
OBJ	--	1.0000e+20	1.0000e+14	AIR		
1	7.575000	3.600000	3.000003 S	KERATOM	M	*
AST	--	--	2.640233 AS	KERATOM	P	
3	--	0.900000	2.640233 S	AQ	M	
4	--	25.489815 S	2.550191 S	VIT	M	
IMS	--	--	2.2444e-05 S			

*CONIC AND POLYNOMIAL ASPHERIC DATA

SRF	CC	AD	AE	AF	AG
1	-0.141350	--	--	--	--

*REFRACTIVE INDICES

SRF	GLASS	RN1	RN2	RN3	VNBR	TCE
0	AIR	1.000000	1.000000	1.000000	--	--
1	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
2	KERATOM	1.337500	1.676807	1.207932	0.719807	236.000000
3	AQ	1.336000	1.675279	1.206444	0.716671	236.000000
4	VIT	1.336000	1.675279	1.206444	0.716671	236.000000
5	IMAGE SURFACE					

*WAVELENGTHS

CURRENT	WV1/WW1	WV2/WW2	WV3/WW3
1	0.587560	0.486130	0.656270
	1.000000	1.000000	1.000000

The Z11 cornea is a 1-surface eye model. For the lens design, a 2-surface model is used in order to have the lens in aquaous. It was verified that the 2 eye models have the same wavefront aberrations:
(OSLO notation)

coefficient	1 surface	2 surface	Difference
Z0	0.001173714	0.001174047	0.03%
Z1	0	0	
Z2	0	0	
Z3	0.001769161	0.001769673	0.03%
Z4	0	0	
Z5	0	0	
Z6	0	0	
Z7	0	0	
Z8	0.000601207	0.000601396	0.03%
Z9	0	0	
Z10	0	0	
Z11	0	0	
Z12	0	0	
Z13	0	0	
Z14	0	0	
Z15	5.78493E-08	5.79E-08	0.16%
Z16	0	0	
Z17	0	0	
Z18	0	0	
Z19	0	0	
Z20	0	0	
Z21	0	0	
Z22	0	0	
Z23	0	0	
Z24	2.40715E-08	2.43E-08	0.76%
Z25	0	0	
Z26	0	0	
Z27	0	0	
Z28	0	0	
Z29	0	0	
Z30	0	0	
Z31	0	0	
Z32	0	0	
Z33	0	0	
Z34	0	0	
Z35	-6.60344E-10	-6.48E-10	-0.41%
Z36	0	0	

Appendix 2: OSLO Zernike operands

The operands, used for optimizing the lens are calculated in a procedure 'oprds_Zernike2'. The procedure is stored in the file 'optimize_Z_haw.ccl':

```
cmd oprds_Zernike2()
// Define Zernike terms as operands for opimization in 2 configurations
{
	set_preference(output_text, off);
	cfg 1;			// Configuration 1
	sop 0;tra all 1;	// om te voorkomen dat OSLO vastloopt bij diffractielenzen
	spd mon none +SDAD 1;	// SDAD=APDIV in lensfile (setup) bepalend voor de
rekensnelheid!!
	ssbuf_reset();zer bf 1 36;
	Ocm[0] = a1**2; // OSLO Zernike Piston term Z0
	Ocm[1] = a2**2; // Z1 TILT
	Ocm[2] = a3**2; // Z2 TILT
	Ocm[3] = a4**2; // Z3 DEFOCUS
	Ocm[4] = a5**2; // Z4 ASTIGMATISM
	Ocm[5] = a6**2; // Z5 ASTIGMATISM
	Ocm[6] = a7**2; // Z6 COMA
	Ocm[7] = a8**2; // Z7 COMA
	Ocm[8] = a9**2; // Z8 3rd ORDER SPHERICAL ABERRATION
	Ocm[9] = a11**2;	// Z9  TREFOIL
	Ocm[10] = a11**2;	// Z10 TREFOIL
	Ocm[11] = a12**2;	// Z11
	Ocm[12] = a13**2;	// Z12
	Ocm[13] = a14**2;	// Z13
	Ocm[14] = a15**2;	// Z14
	Ocm[15] = a16**2;	// Z15
	Ocm[16] = a17**2;	// Z16
	Ocm[17] = a18**2;	// Z17
	Ocm[18] = a19**2;	// Z18
	Ocm[19] = a20**2;	// Z19
	Ocm[20] = a21**2;	// Z20
	Ocm[21] = a22**2;	// Z21
	Ocm[22] = a23**2;	// Z22
	Ocm[23] = a24**2;	// Z23
	Ocm[24] = a25**2;	// Z24
	Ocm[25] = a26**2;	// Z25
	Ocm[26] = a27**2;	// Z26
	Ocm[27] = a28**2;	// Z27
	Ocm[28] = a29**2;	// Z28
	Ocm[29] = a30**2;	// Z29
	Ocm[30] = a31**2;	// Z30
	Ocm[31] = a32**2;	// Z31
	Ocm[32] = a33**2;	// Z32
	Ocm[33] = a34**2;	// Z33
	Ocm[34] = a35**2;	// Z34
	Ocm[35] = a36**2;	// Z35
	Ocm[36] = a37**2;	// Z36
	set_preference(output_text, on);
	set_preference(output_text, off);
	cfg 2;			// Configuration 2
	sop 0;tra all 1;	// om te voorkomen dat OSLO vastloopt bij diffractielenzen
	spd mon none +SDAD 1;	// SDAD=APDIV in lensfile (setup) bepalend voor de
rekensnelheid!!
	ssbuf_reset();zer bf 1 36;
	Ocm[0] += a1**2;	// OSLO Zernike Piston term Z0
	Ocm[1] += a2**2;	// Z1 TILT
	Ocm[2] += a3**2;	// Z2 TILT
	Ocm[3] += a4**2;	// Z3 DEFOCUS
	Ocm[4] += a5**2;	// Z4 ASTIGMATISM
	Ocm[5] += a6**2;	// Z5 ASTIGMATISM
	Ocm[6] += a7**2;	// Z6 COMA
	Ocm[7] += a8**2;	// Z7 COMA
	Ocm[8] += a9**2;	// Z8 3rd ORDER SPHERICAL ABERRATION
	Ocm[9] += a11**2;	// Z9  TREFOIL
	Ocm[10] += a11**2;	// Z10 TREFOIL
	Ocm[11] += a12**2;	// Z11
	Ocm[12] += a13**2;	// Z12
	Ocm[13] += a14**2;	// Z13
```

```
        Ocm[14] += a15**2;      // Z14
        Ocm[15] += a16**2;      // Z15
        Ocm[16] += a17**2;      // Z16
        Ocm[17] += a18**2;      // Z17
        Ocm[18] += a19**2;      // Z18
        Ocm[19] += a20**2;      // Z19
        Ocm[20] += a21**2;      // Z20
        Ocm[21] += a22**2;      // Z21
        Ocm[22] += a23**2;      // Z22
        Ocm[23] += a24**2;      // Z23
        Ocm[24] += a25**2;      // Z24
        Ocm[25] += a26**2;      // Z25
        Ocm[26] += a27**2;      // Z26
        Ocm[27] += a28**2;      // Z27
        Ocm[28] += a29**2;      // Z28
        Ocm[29] += a30**2;      // Z29
        Ocm[30] += a31**2;      // Z30
        Ocm[31] += a32**2;      // Z31
        Ocm[32] += a33**2;      // Z32
        Ocm[33] += a34**2;      // Z33
        Ocm[34] += a35**2;      // Z34
        Ocm[35] += a36**2;      // Z35
        Ocm[36] += a37**2;      // Z36
        set_preference(output_text, on);
}
```

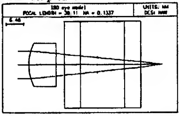
Appendix 3: PMMA Z9000 cornea in ISO fixture

ISO uses a cornea in front of a wet cell. The ISO cornea can be replaced by a PMMA cornea. The PMMA cornea has to generate a wavefront equivalent to the wavefront in the Z9000 model eye. This is caracterised by the working f-number and the wavefront aberrations (Zernike terms).

The Z9000 model eye is caracterized by:
Aperture diameter of the cornea = 6.0 mm
Corresponding aperture radius at the IOL position: 2.640233 mm
Working f-number = 3.740741
Wavefront aberration (OSLO notation): Z8 = 0.000601 mm
Z15 = $5.7840*10^{-6}$ mm
(Z24 = $2.4*10^{-8}$ mm)

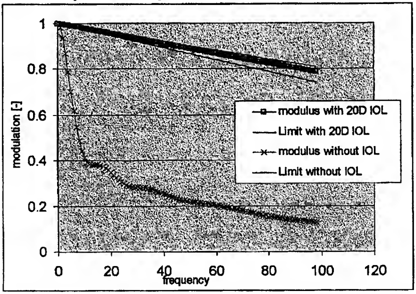
The ISO eyemodel is described in ISO/DIS 11979-2. Only the wet cell with the aperture is used, with pure water as medium. The PMMA cornea has a central thickness of 10.0mm and is placed 3.0mm in front of the cell. The refractive index of the rod PMMA was measured as 1.4872 (22°C, 546.1nm). For the calculation of the working f-number and the wavefront aberrations, the right window is taken away, so that the system focusses in water. The working f-number determines the radius of the convex-plano PMMA cornea: R=18.5683 mm.
The aspherical components of the PMMA surface are optimized to produce the Z9000 wavefront aberrations, which resulted in:

cc = -0.177999
ad = $+5.1185*10^{-6}$
ae = $+3.3540*10^{-9}$



When the measurement is taken with the focus in air (the real situation), the resulting wavefront aberration is slighly higher (4% for Z8). When a 20.0 diopter Z9000 IOL is placed in the cell, 94% of the wavefront aberration (Z8) is corrected. In the Z9000 design eyemodel, a 20.0D IOL corrects 99% of the wavefront aberration (Z8).

MTF for a 5.1mm aperture (at the IOL position):



Verification: PMMA cornea for ISO-fixture, with focus in water.

```
Apdiv 97.10
Zernike in mm
Spot diagram in image space
Pupil 2.640233

*LENS DATA
PMMA Z9000 cornea in ISO fixture
 SRF      RADIUS      THICKNESS    APERTURE RADIUS      GLASS  SPE  NOTE
 OBJ        --        1.0000e+20    1.0000e+14            AIR

  1     18.568300     10.000000      8.000000         PMMA_ROD   *
  2        --          3.000000      8.000000             AIR

  3        --          6.000000     16.000000             BK7 C
  4        --          6.250000     16.000000           WATER C
 AST       --         26.355802 S    2.640233 AS        WATER C
 IMS       --            --         3.8112e-05 S

*CONIC AND POLYNOMIAL ASPHERIC DATA
 SRF        CC          AD          AE          AF          AG
  1     -0.177999  5.1185e-06  3.3540e-09      --          --

*ZERNIKE ANALYSIS
 WAVELENGTH 1
 Positive angle A is a rotation from the +y axis toward the +x axis.
    0.001173: [0]  1
       --    : [1]  RCOSA
       --    : [2]  RSINA
    0.001769: [3]  2R^2 - 1
       --    : [4]  R^2COS2A
       --    : [5]  R^2SIN2A
       --    : [6]  (3R^2 - 2)RCOSA
       --    : [7]  (3R^2 - 2)RSINA
    0.000601: [8]  6R^4 - 6R^2 + 1
       --    : [9]  R^3COS3A
       --    : [10] R^3SIN3A
       --    : [11] (4R^2 - 3)R^2COS2A
       --    : [12] (4R^2 - 3)R^2SIN2A
       --    : [13] (10R^4 - 12R^2 + 3)RCOSA
       --    : [14] (10R^4 - 12R^2 + 3)RSINA
  5.7840e-06: [15] 20R^6 - 30R^4 + 12R^2 - 1
       --    : [16] R^4COS4A
       --    : [17] R^4SIN4A
       --    : [18] (5R^2 - 4)R^3COS3A
       --    : [19] (5R^2 - 4)R^3SIN3A
       --    : [20] (15R^4 - 20R^2 + 6)R^2COS2A
       --    : [21] (15R^4 - 20R^2 + 6)R^2SIN2A
       --    : [22] (35R^6 - 60R^4 + 30R^2 - 4)RCOSA
       --    : [23] (35R^6 - 60R^4 + 30R^2 - 4)RSINA
  2.3253e-08: [24] 70R^8 - 140R^6 + 90R^4 - 20R^2 + 1
       --    : [25] R^5COS5A
       --    : [26] R^5SIN5A
       --    : [27] (6R^2 - 5)R^4COS4A
       --    : [28] (6R^2 - 5)R^4SIN4A
       --    : [29] (21R^4 - 30R^2 + 10)R^3COS3A
       --    : [30] (21R^4 - 30R^2 + 10)R^3SIN3A
       --    : [31] (56R^6 - 105R^4 + 60R^2 - 10)R^2COS2A
       --    : [32] (56R^6 - 105R^4 + 60R^2 - 10)R^2SIN2A
       --    : [33] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RCOSA
       --    : [34] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RSINA
 -6.0838e-10: [35] 252R^10 - 630R^8 + 560R^6 - 210R^4 + 30R^2 - 1
       --    : [36] 924R^12 - 2772R^10 + 3150R^8 - 1680R^6 + 420R^4 - 42R^2 + 1
RMS OPD    0.001056   ERROR  7.0480e-11
```

Verification: PMMA cornea for ISO-fixture, with focus in air.

```
*LENS DATA
PMMA Z9000 cornea in ISO fixture
 SRF      RADIUS      THICKNESS    APERTURE RADIUS      GLASS  SPE  NOTE
```

```
OBJ         --          1.0000e+20    1.0000e+14            AIR

 1     18.568300       10.000000      8.000000         PMMA_ROD   *
 2         --           3.000000      8.000000              AIR

 3         --           6.000000     16.000000              BK7 C
 4         --           6.250000     16.000000            WATER C
AST        --             --          2.640233 AS         WATER C
 6         --          10.000000      2.640233 S          WATER C
 7         --           6.000000     16.000000              BK7 C
 8         --           8.306948 S   16.000000              AIR

IMS        --             --         3.8112e-05 S

*CONIC AND POLYNOMIAL ASPHERIC DATA
 SRF        CC           AD           AE          AF          AG
  1     -0.177999  5.1185e-06  3.3540e-09         --          --

*ZERNIKE ANALYSIS
 WAVELENGTH 1
 Positive angle A is a rotation from the +y axis toward the +x axis.
    0.001212: [0]  1
      --    : [1]  RCOSA
      --    : [2]  RSINA
    0.001828: [3]  2R^2 - 1
      --    : [4]  R^2COS2A
      --    : [5]  R^2SIN2A
      --    : [6]  (3R^2 - 2)RCOSA
      --    : [7]  (3R^2 - 2)RSINA
    0.000623: [8]  6R^4 - 6R^2 + 1
      --    : [9]  R^3COS3A
      --    : [10] R^3SIN3A
      --    : [11] (4R^2 - 3)R^2COS2A
      --    : [12] (4R^2 - 3)R^2SIN2A
      --    : [13] (10R^4 - 12R^2 + 3)RCOSA
      --    : [14] (10R^4 - 12R^2 + 3)RSINA
  6.7871e-06: [15] 20R^6 - 30R^4 + 12R^2 - 1
      --    : [16] R^4COS4A
      --    : [17] R^4SIN4A
      --    : [18] (5R^2 - 4)R^3COS3A
      --    : [19] (5R^2 - 4)R^3SIN3A
      --    : [20] (15R^4 - 20R^2 + 6)R^2COS2A
      --    : [21] (15R^4 - 20R^2 + 6)R^2SIN2A
      --    : [22] (35R^6 - 60R^4 + 30R^2 - 4)RCOSA
      --    : [23] (35R^6 - 60R^4 + 30R^2 - 4)RSINA
  2.0654e-08: [24] 70R^8 - 140R^6 + 90R^4 - 20R^2 + 1
      --    : [25] R^5COS5A
      --    : [26] R^5SIN5A
      --    : [27] (6R^2 - 5)R^4COS4A
      --    : [28] (6R^2 - 5)R^4SIN4A
      --    : [29] (21R^4 - 30R^2 + 10)R^3COS3A
      --    : [30] (21R^4 - 30R^2 + 10)R^3SIN3A
      --    : [31] (56R^6 - 105R^4 + 60R^2 - 10)R^2COS2A
      --    : [32] (56R^6 - 105R^4 + 60R^2 - 10]R^2SIN2A
      --    : [33] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RCOSA
      --    : [34] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RSINA
 -1.2840e-09: [35] 252R^10 - 630R^8 + 560R^6 - 210R^4 + 30R^2 - 1
      --    : [36] 924R^12 - 2772R^10 + 3150R^8 - 1680R^6 + 420R^4 - 42R^2 + 1
RMS OPD     0.001092    ERROR       --
```

Verification: PMMA cornea for ISO-fixture, with focus in air, with Z9000 IOL, 20.0D

```
*LENS DATA
PMMA Z9000 cornea in ISO fixture
 SRF       RADIUS       THICKNESS    APERTURE RADIUS      GLASS   SPE  NOTE
 OBJ         --         1.0000e+20     1.0000e+14           AIR

  1      18.568300      10.000000      8.000000         PMMA_ROD   *
  2          --          3.000000      8.000000             AIR
```

```
 3       --          6.000000     16.000000             BK7 C
 4       --          6.250000     16.000000           WATER C
AST      --            --          2.640233 AS        WATER C
 6    12.154000      1.125000      2.640233 S           HRI   *
 7   -12.154000      8.875000      2.516362 S         WATER C
 8       --          6.000000     16.000000             BK7 C
 9       --          2.914830 S   16.000000             AIR

IMS      --            --          2.7366e-05 S

*CONIC AND POLYNOMIAL ASPHERIC DATA
 SRF        CC           AD          AE           AF          AG
  1     -0.177999  5.1185e-06  3.3540e-09        --          --
  6     -1.018550   -0.000899 -1.1400e-05        --          --

*ZERNIKE ANALYSIS
 WAVELENGTH 1
 Positive angle A is a rotation from the +y axis toward the +x axis.
 -5.7675e-05: [0]  1
      --    : [1]  RCOSA
      --    : [2]  RSINA
 -9.0472e-05: [3]  2R^2 - 1
      --    : [4]  R^2COS2A
      --    : [5]  R^2SIN2A
      --    : [6]  (3R^2 - 2)RCOSA
      --    : [7]  (3R^2 - 2)RSINA
 -3.5900e-05: [8]  6R^4 - 6R^2 + 1
      --    : [9]  R^3COS3A
      --    : [10] R^3SIN3A
      --    : [11] (4R^2 - 3)R^2COS2A
      --    : [12] (4R^2 - 3)R^2SIN2A
      --    : [13] (10R^4 - 12R^2 + 3)RCOSA
      --    : [14] (10R^4 - 12R^2 + 3)RSINA
 -3.4880e-06: [15] 20R^6 - 30R^4 + 12R^2 - 1
      --    : [16] R^4COS4A
      --    : [17] R^4SIN4A
      --    : [18] (5R^2 - 4)R^3COS3A
      --    : [19] (5R^2 - 4)R^3SIN3A
      --    : [20] (15R^4 - 20R^2 + 6)R^2COS2A
      --    : [21] (15R^4 - 20R^2 + 6)R^2SIN2A
      --    : [22] (35R^6 - 60R^4 + 30R^2 - 4)RCOSA
      --    : [23] (35R^6 - 60R^4 + 30R^2 - 4)RSINA
 -4.1784e-07: [24] 70R^8 - 140R^6 + 90R^4 - 20R^2 + 1
      --    : [25] R^5COS5A
      --    : [26] R^5SIN5A
      --    : [27] (6R^2 - 5)R^4COS4A
      --    : [28] (6R^2 - 5)R^4SIN4A
      --    : [29] (21R^4 - 30R^2 + 10)R^3COS3A
      --    : [30] (21R^4 - 30R^2 + 10)R^3SIN3A
      --    : [31] (56R^6 - 105R^4 + 60R^2 - 10)R^2COS2A
      --    : [32] (56R^6 - 105R^4 + 60R^2 - 10)R^2SIN2A
      --    : [33] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RCOSA
      --    : [34] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RSINA
 -3.3549e-08: [35] 252R^10 - 630R^8 + 560R^6 - 210R^4 + 30R^2 - 1
 -1.3002e-09: [36] 924R^12 - 2772R^10 + 3150R^8 - 1680R^6 + 420R^4 - 42R^2 + 1
RMS OPD  5.4662e-05   ERROR  1.8430e-11
```

PMMA/Z9000 cornea for PPG-fixture.

```
Apdiv 97.10
Zernike in mm
Spot diagram in image space
Pupil 2.640233

*LENS DATA
PMMA Z9000 CORNEA PPG_fixture n=100
 SRF       RADIUS       THICKNESS    APERTURE RADIUS       GLASS  SPE  NOTE
 OBJ         --         1.0000e+20    1.0000e+14             AIR
  1      11.047000       4.000000      3.000000             PMMA   *
  2      1.0000e+26      0.100000      2.650289 S          WATER
 AST         --            --          2.640233 AS         PUPIL
```

4	--	1.700000	2.640233 S	WATER
5	--	24.556458 S	2.469290 S	WATER
IMS	--	-0.140000	0.014100 S	

*CONIC AND POLYNOMIAL ASPHERIC DATA

SRF	CC	AD	AE	AF	AG
1	0.512084	-9.0182e-06	-4.1412e-08	--	--

```
*ZERNIKE ANALYSIS
 WAVELENGTH 1
 Positive angle A is a rotation from the +y axis toward the +x axis.
    0.000685: [0]  1
       --    : [1]  RCOSA
       --    : [2]  RSINA
    0.001280: [3]  2R^2 - 1
       --    : [4]  R^2COS2A
       --    : [5]  R^2SIN2A
       --    : [6]  (3R^2 - 2)RCOSA
       --    : [7]  (3R^2 - 2)RSINA
    0.000603: [8]  6R^4 - 6R^2 + 1
       --    : [9]  R^3COS3A
       --    : [10] R^3SIN3A
       --    : [11] (4R^2 - 3)R^2COS2A
       --    : [12] (4R^2 - 3)R^2SIN2A
       --    : [13] (10R^4 - 12R^2 + 3)RCOSA
       --    : [14] (10R^4 - 12R^2 + 3)RSINA
  9.0025e-06: [15] 20R^6 - 30R^4 + 12R^2 - 1
       --    : [16] R^4COS4A
       --    : [17] R^4SIN4A
       --    : [18] (5R^2 - 4)R^3COS3A
       --    : [19] (5R^2 - 4)R^3SIN3A
       --    : [20] (15R^4 - 20R^2 + 6)R^2COS2A
       --    : [21] (15R^4 - 20R^2 + 6)R^2SIN2A
       --    : [22] (35R^6 - 60R^4 + 30R^2 - 4)RCOSA
       --    : [23] (35R^6 - 60R^4 + 30R^2 - 4)RSINA
  1.4315e-07: [24] 70R^8 - 140R^6 + 90R^4 - 20R^2 + 1
       --    : [25] R^5COS5A
       --    : [26] R^5SIN5A
       --    : [27] (6R^2 - 5)R^4COS4A
       --    : [28] (6R^2 - 5)R^4SIN4A
       --    : [29] (21R^4 - 30R^2 + 10)R^3COS3A
       --    : [30] (21R^4 - 30R^2 + 10)R^3SIN3A
       --    : [31] (56R^6 - 105R^4 + 60R^2 - 10)R^2COS2A
       --    : [32] (56R^6 - 105R^4 + 60R^2 - 10)R^2SIN2A
       --    : [33] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RCOSA
       --    : [34] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RSINA
  1.9291e-09: [35] 252R^10 - 630R^8 + 560R^6 - 210R^4 + 30R^2 - 1
       --    : [36] 924R^12 - 2772R^10 + 3150R^8 - 1680R^6 + 420R^4 - 42R^2 + 1
RMS OPD    0.000787   ERROR  8.8271e-11
```

PMMA/Z9000 cornea for PPG-fixture with 20.0D Z9000 lens.

Apdiv 97.10
Zernike in mm
Spot diagram in image space
IOL pupil 2.640233

*LENS DATA
PMMA Z9000 CORNEA PPG_fixture n=100

SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPE	NOTE
OBJ	--	1.0000e+20	1.0000e+14	AIR		
1	11.047000	4.000000	3.000000	PMMA	*	
2	1.0000e+26	0.100000	2.650289 S	WATER		
AST	--	--	2.640233 AS	PUPIL		
4	*--*	*1.700000*	*2.640233 S*	*WATER*		
5	12.154000	1.103000	2.469290 S	HRI	*	
6	-12.154000	17.052946 S	3.000000	WATER		
IMS	--	-0.140000	0.019298 S			

*CONIC AND POLYNOMIAL ASPHERIC DATA

```
SRF        CC          AD          AE          AP         AG
 1      0.512084 -9.0182e-06 -4.1412e-08      --         --
 5     -1.018548   -0.000899 -1.1412e-05      --         --

*ZERNIKE ANALYSIS
WAVELENGTH 1
Positive angle A is a rotation from the +y axis toward the +x axis.
  -0.000720: [0]  1
     --    : [1]  RCOSA
     --    : [2]  RSINA
  -0.000632: [3]  2R^2 - 1
     --    : [4]  R^2COS2A
     --    : [5]  R^2SIN2A
     --    : [6]  (3R^2 - 2)RCOSA
     --    : [7]  (3R^2 - 2)RSINA
 9.2891e-05: [8]  6R^4 - 6R^2 + 1
     --    : [9]  R^3COS3A
     --    : [10] R^3SIN3A
     --    : [11] (4R^2 - 3)R^2COS2A
     --    : [12] (4R^2 - 3)R^2SIN2A
     --    : [13] (10R^4 - 12R^2 + 3)RCOSA
     --    : [14] (10R^4 - 12R^2 + 3)RSINA
 4.8164e-06: [15] 20R^6 - 30R^4 + 12R^2 - 1
     --    : [16] R^4COS4A
     --    : [17] R^4SIN4A
     --    : [18] (5R^2 - 4)R^3COS3A
     --    : [19] (5R^2 - 4)R^3SIN3A
     --    : [20] (15R^4 - 20R^2 + 6)R^2COS2A
     --    : [21] (15R^4 - 20R^2 + 6)R^2SIN2A
     --    : [22] (35R^6 - 60R^4 + 30R^2 - 4)RCOSA
     --    : [23] (35R^6 - 60R^4 + 30R^2 - 4)RSINA
-9.1973e-09: [24] 70R^8 - 140R^6 + 90R^4 - 20R^2 + 1
     --    : [25] R^5COS5A
     --    : [26] R^5SIN5A
     --    : [27] (6R^2 - 5)R^4COS4A
     --    : [28] (6R^2 - 5)R^4SIN4A
     --    : [29] (21R^4 - 30R^2 + 10)R^3COS3A
     --    : [30] (21R^4 - 30R^2 + 10)R^3SIN3A
     --    : [31] (56R^6 - 105R^4 + 60R^2 - 10)R^2COS2A
     --    : [32] (56R^6 - 105R^4 + 60R^2 - 10)R^2SIN2A
     --    : [33] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RCOSA
     --    : [34] (126R^8 - 280R^6 + 210R^4 - 60R^2 + 5)RSINA
-1.1709e-08: [35] 252R^10 - 630R^8 + 560R^6 - 210R^4 + 30R^2 - 1
-4.6305e-10: [36] 924R^12 - 2772R^10 + 3150R^8 - 1680R^6 + 420R^4 - 42R^2 + 1
RMS OPD     0.000367    ERROR       --
```

Appendix 4: Measurement procedure of the lens power in the waterbath

The lenses were measured for optical power in a water bath. The actual back focal length (BFL) was used as the measure of lens power in water. The lens is focused at maximum MTF at 50c/mm. The measurement is time consuming, due to the fluctuations of the MTF values. A manual through focus measurement was performed, so that the interpolated best focus could be determined off-line. For each value, an extensive settling time of 5 minutes or more was exercised.

Determination of the lens power in vivo consists of the followig steps:

1. Through focus measurement in a waterbath
2. Determination of the actual BFL by interpolation
3. From the actual BFL, determine the effective focal length (EFL) by adding the longitudinal spherical aberration and the position of the 2nd principle plane.
4. Determine the lens power in water, from the equation *1.3406/EFL*
5. Determine the lens power in vivo, from the theoretical relationship between lens power in water and lens power in vivo.

1. Through focus measurement in a waterbath

A manual through focus MTF at 50c/mm was measured in a waterbath. Characteristics of the measurement set-up:

- Aperture 3mm
- Water with PEG200, refractive index 1.3406
- Slit width 10 micrometer
- 10X objective lens
- 1 through focus measurement per lens
- 5 to 8 focus positions for each focal point

2. Determination of the actual BFL by interpolation

In order to be able to make an interpolation, a curve was fit through the through-focus response. For this purpose, a square double log function was used:

$$log(MTF) = b_0 + b_1 * (log(BFL)) + b_2 * (log(BFL))^2$$

This function is bell-shaped by nature, similar to a normal through-focus response. The maximum of the curve is detrmined by $log(BFL) = -½(b_1/b_2)$

3. From the actual BFL, determine the effective focal length.

In order to find the EFL, the spherical aberration has to be added to the BFL, as well as the distance between the 2nd principle plane and the posterior lens surface.

The longitudinal spherical aberration (LSA) of a bifocal lens in a waterbath is assumed identical to its monofocal equivalent. This means that the LSA can be calculated with OSLO, using the same lens geometry without the diffraction pattern, and using the appropriate refractive indices as applicable under the measuring conditions. It means that the monofocal Z9000 lens design can be used in the calculations (only this prototype lens was measured in the waterbath). Figure 4.1. shows the OSLO results for a 20.0D lens and the results for the 3 measured lens powers are sumarised in figure 4-2.

```
*LENS DATA
Design4ZMO_200
 SRF       RADIUS        THICKNESS    APERTURE RADIUS        GLASS   SPE  NOTE
 OBJ         --         1.0000e+20     1.0000e+14          WATERMO
 AST     12.154000        1.125070       1.500000 AS       HRISILMO    *
  2     -12.154000       65.748017 S     3.000000          WATERMO
 IMS         --              --      V  6.6265e-05 S

*CONIC AND POLYNOMIAL ASPHERIC DATA
 SRF         CC            AD            AE            AF            AG
  1      -1.018550     -0.000899  -1.1418e-05         --            --

*WAVELENGTHS
CURRENT  WV1/WW1      WV2/WW2       WV3/WW3
   1     0.550000     0.550000      0.550000
         1.000000     1.000000      1.000000

*REFRACTIVE INDICES
 SRF       GLASS             RN1          RN2          RN3         VNBR        TCE
  0       WATERMO         1.340563     1.340563     1.340563        --          --
  1       HRISILMO        1.463984     1.463984     1.463984        --      236.000000
  2       WATERMO         1.340563     1.340563     1.340563        --      236.000000
  3       IMAGE SURFACE

minimum focus position:      --
maximum focus position:    5.000000
      number of steps:    500

a = max MTF(f=50): 0.3557
b =     at defocus: 1.4000 mm
```

Figure 4-1. OSLO output for a 20.0D lens of model Z9000, in the waterbath.

Nominal Power	Anterior radius	Posterior radius	Central Thickness	Total Power	Anterior Power	Spherical aberration
15	16.225	-16.225	1.027	15.17	7.61	2.75
19	12.797	-12.797	1.106	19.22	9.64	1.54
20	12.154	-12.154	1.125	20.23	10.16	1.40
24	10.117	-10.117	1.203	24.28	12.20	0.99
26	9.333	-9.333	1.242	26.30	13.22	0.86
30	8.075	-8.075	1.319	30.36	15.28	0.67
Units	mm	mm	mm	D	D	mm

Figure 4.2. Spherical aberration for different lens powers. Note that the spherical aberration is positive for all lens powers. This is opposite to the normal spherical lenses.

The position of the 2[nd] principle plane is calculated using the paraxial equations:

$$H" = \frac{\eta_{med}}{\eta_{IOL}} * \frac{P_1}{P} * CT$$

H" = distance between 2[nd] principle plane and the posterior lens surface
η_{med} = refractive index of the surrounding medium
η_{IOL} = refractive index of the lens
P_1 = power of the front surface of the lens
P = total power of the lens
CT = central thickness of the lens
Application for the monofocal Z9000 lens model results in values of 0.471, 0.517 and 0.572mm for 15.0D, 20.0D and 26D lenses respectively. According the definition of bifocal lens power, H" is equal for far and near vision[8].

4. Determine the lens power in water

The lens power in water is defined by η_{med}/EFL, with η_{med}=1.3406 and EFL expressed in meter units. The result is not exactly identical as the lens power in vivo.

5. Determine the lens power in vivo

The lens power in vivo is defined by the lens geometry and the nominal refractive indices η_{med}=1.336 and η_{IOL}=1.458. The lens power under MO-lab conditions is defined by the lens geometry and the nominal refractive indices η_{med}=1.3406 and η_{IOL}=1.46398. Using the thick-lens-equation for both situations, the relationship between the two can be determined (figure 4-3).

			η_{IOL}	1.46398	1.458
			η_{med}	1.34056	1.336
Power	R a	R p	Central Thickness	MO-lab Power T.L.E	In-vivo Power T.L.E
5.0	48.786	-48.786	0.83	5.06	5.00
6.0	40.632	-40.632	0.85	6.07	6.00
7.0	34.821	-34.821	0.87	7.08	7.00
8.0	30.463	-30.463	0.89	8.09	8.00
9.0	27.074	-27.074	0.91	9.10	9.00
10.0	24.362	-24.362	0.93	10.12	10.00
10.5	23.200	-23.200	0.94	10.62	10.50
11.0	22.143	-22.143	0.95	11.13	11.00
11.5	21.178	-21.178	0.96	11.63	11.50
12.0	20.294	-20.294	0.97	12.14	12.00
12.5	19.480	-19.480	0.98	12.64	12.50
13.0	18.729	-18.729	0.99	13.15	13.00
13.5	18.033	-18.033	1.00	13.66	13.50
14.0	17.387	-17.387	1.01	14.16	14.00
14.5	16.786	-16.786	1.02	14.67	14.50
15.0	16.225	-16.225	1.03	15.17	15.00
15.5	15.699	-15.699	1.04	15.68	15.50
16.0	15.207	-15.207	1.05	16.19	16.00
16.5	14.745	-14.745	1.06	16.69	16.50
17.0	14.309	-14.309	1.07	17.20	17.00
17.5	13.899	-13.899	1.08	17.70	17.50
18.0	13.511	-13.511	1.09	18.21	18.00
18.5	13.144	-13.144	1.10	18.71	18.50
19.0	12.797	-12.797	1.11	19.22	19.00
19.5	12.467	-12.467	1.12	19.73	19.50
20.0	12.154	-12.154	1.13	20.23	20.00
20.5	11.856	-11.856	1.13	20.74	20.50
21.0	11.572	-11.572	1.14	21.24	21.00
21.5	11.301	-11.301	1.15	21.75	21.50
22.0	11.043	-11.043	1.16	22.25	22.00
22.5	10.796	-10.796	1.17	22.76	22.50
23.0	10.560	-10.560	1.18	23.27	23.00
23.5	10.334	-10.334	1.19	23.77	23.50
24.0	10.117	-10.117	1.20	24.28	24.00
24.5	9.909	-9.909	1.21	24.78	24.50
25.0	9.709	-9.709	1.22	25.29	25.00
25.5	9.517	-9.517	1.23	25.79	25.50
26.0	9.333	-9.333	1.24	26.30	26.00
26.5	9.155	-9.155	1.25	26.81	26.50
27.0	8.984	-8.984	1.26	27.31	27.00
27.5	8.819	-8.819	1.27	27.82	27.50
28.0	8.659	-8.659	1.28	28.33	28.00
28.5	8.505	-8.505	1.29	28.84	28.51
29.0	8.357	-8.357	1.30	29.34	29.01
29.5	8.214	-8.214	1.31	29.85	29.51
30.0	8.076	-8.076	1.32	30.36	30.01

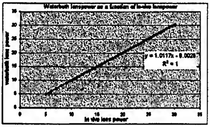


Figure 4-3. Relationship between the lens power under MO-lab conditions (waterbath) and in vivo lens power. T.L.E = thick-lens-equation.

Appendix 5: Test of the light distribution with different step heights.

In order to determine the optimal stepheight of the diffractive profile, 3 different stepheights were tested of a 20.0D bifocal diffractive design. The target is a 50:50 light distribution.

Lens power	20.0 D	20.0 D	20.0 D
Anterior radius	12.154	12.154	12.154
Posterior radius	-12.586	-12.586	-12.586
Central thickness	1.125	1.125	1.125
R_1	0.513	0.513	0.513
k	0.7065	0.6754	0.6443
cc	-1.01855	-1.01855	-1.01855
ad	0.0010482	0.0010482	0.0010482
ae	-5.7596E-06	-5.7596E-06	-5.7596E-06
stepheight (µm)	2.50	2.39	2.28

Figure 5-1. Prototype lens designs with different stepheights. These lenses have an aspherical posterior surface to correct for spherical aberration.

The lenses were tested in the Z9000 eye model, using an aperture of 3mm and water with a refractive index of 1.3405. 5 Lenses per type were tested (MO-lab service request F030). The image was focused at a maximum MTF at 50c/mm. The 4 central pixels with maximum intensity were used as a measure of the amount of light in each focus. The ratio of near and far focus determines the light distribution.

k	0.7065	0.6754	0.6443
stepheight	2.50	2.39	2.28
Lens 1	44.7%	49.9%	50.9%
Lens 2	44.8%	48.6%	50.2%
Lens 3	45.1%	48.9%	51.1%
Lens 4	46.1%	47.9%	50.2%
Lens 5	47.8%	48.2%	50.2%
Average	45.7%	48.7%	50.5%
Stdev	1.3%	0.8%	0.5%

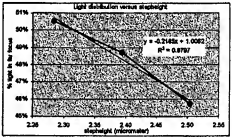


Figure 5-2. Measured percent of light in the FAR-focus versus stepheight.

The measurements show a good linearity between stepheight and light distribution. According this data, the optimal stepheight for a 50:50% light distribution is 2.32 micrometer, which correspoinds to a k-value of 0.6536.

The MTF distribution showed to be closely related to the light distribution, though the two are not identical. See figure 5-3.

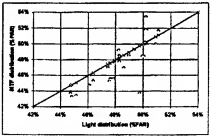


Figure 5-3. MTF(50c/mm) distribution versus light distribution.

Appendix 6: Refractive indices

The performance of diffractive lenses is highly dependent on the refractive indices of the lens material and the surrounding medium and especially the difference between these two. Therefore, special care is taken to use the most accurate values for the HRI material. Furthermore, the refractive index of the water, used for measurements in the MO-lab is adjusted to the most appropriate value.
For the calculation of the image quality in vivo, the generally accepted refractive index of aqueous of 1.336 is applied. For the silicone HRI material, the measured values of the AR lab were taken as the reference ('Dispersion of HRI material', H. Weeber, PG report 2390). This is based on measurements of several batches of HRI material and it includes the dispersion of the material. The result is a refractive index of 1.45942 at 550nm and 35°C.
For the MO-lab conditions, the refractive index at 22°C and 550nm was determined using measurement data of HRI at different temperatures. This data is available in the QA-lab for a wavelength of 589nm (see figure 6-1). It is assumed that this difference of refractive index is also valid for a wavelength of 550nm.

Batch	11103	11102	11101	11003	11002	11001	11006	11005	11004	10903	10902	10901	10706	10705	10704	10703	10702	10701	Average
date	7-2-02	7-2-02	7-2-02	30-1-02	30-1-02	30-1-02	14-1-02	14-1-02	14-1-02	12-12-01	12-12-01	12-12-01	8-11-01	8-11-01	8-11-01	13-9-01	13-9-01	13-9-01	
n25	1.4615	1.4616	1.4615	1.4618	1.4615	1.4614	1.4615	1.4616	1.4614	1.4612	1.4614	1.4616	1.4618	1.4619	1.4615	1.4621	1.462	1.4619	1.461600
n37	1.4579	1.4581	1.458	1.4579	1.458	1.4572	1.4579	1.4579	1.4579	1.4579	1.4575	1.4573	1.4585	1.4586	1.4581	1.4583	1.4582	1.4581	1.457950

Figure 6-1. Measured refractive indices for 589nm and at temperatures of 25°C and 37°C.
Raw data available at the QA lab.

Applying this to the in vivo index, the refractive index of HRI material under MO-lab conditions is 1.46398.
The refractive index of pure water, 22°C and 550nm, is 1.3342 (Handbook of Chemistry and Physics, Ed. D.R.Lide, CRC Press, Boca Raton (FL)). Under MO-lab conditions, the difference between the lens refractive index and the medium refractive index should be the same as in vivo (0.12342). Therefore, a medium refractive index of 1.34056 has to be used. For practical purposes, a tolerance of ±0.0002 has to be added as a specification.

	Wavelength	Temperature	nlens	nmedium
In vivo	550	35	1.45942	1.336
MO lab	550	22	1.46398	1.34056

Figure 6-2. Refractive indices of the lens (HRI silicone) and the medium (aqueous and water) under invivo and MO-lab conditions, for 550nm.

In order to obtain the correct refractive index of the medium, water is mixed with 5.11% PEG200 (w/w). The mixtures used for the measurements were always measured at the AR lab on the calibrated Abbe refractometer, using a Hg light bulb with 550±10nm filter.

Appendix 7. Raw data

MO-lab measurement data of MTF and BFL measurements of two lens series from pilot plant service request SA020560:

K1 = bifocal foldable with optimized anterior surface
Z9000 K1 = bifocal foldable with Z9000 anterior surface

MECHANICAL OPTICAL LABORATORY

Pharmacia &Upjohn

SERVICE AANVRAAG MECHANISCH/OPTISCH LABORATORIUM

		AANVRAAGNR.:	F050
AANVRAGER:	H.Weeber	AANVRAAGDATUM:	[redacted]
AFDELING:	AR	AFD.CODE:	570
PROJECT/OMSCHRIJVING:	Bifocal Foldable		

TYPE LENS: Prototype Bifocal Foldable

M-/BATCHNUMMER	DIOPTRIE	AANTAL
SA 020560 K1	15.0D	8
SA 020560 K1	20.0D	8
SA 020560 K1	26.0D	8
SA 020560 Z9000 k1	15.0D	8
SA 020560 Z9000 k1	20.0D	8
SA 020560 Z9000 k1	26.0D	8

GEWENSTE METINGEN

MASSA	
OVERALL DIAMETER	
OPTIEK DIAMETER	
BREEDTE-/DIAMETER VAN DE LUSSEN	
DIKTE VAN DE LUSSEN	
STAND VAN DE LUSSEN/STEP HEIGHT	
EDGE THICKNESS	
COMPRESSION FORCE	
AXIAL DISPLACEMENT IN COMPRESSION	
TILT	
AXIAL RIGIDITY	
AMOUNT OF TOUCH	
DECENTRATION	

MTF/EFL	X
BACK FOCAL LENGTH	
DIOPTRIE	
RESOLUTIE	
BURSTTEST	
TREKSTERKTE	

AFWIJKENDE METINGEN

OPMERKINGEN
Z9000 Cornea
brekingsindex v/h water = 1.3406
apertuur 3 en 5 mm
focuseren bij 25 c/mm
waarden bij 25, 50 en 100 c/mm noteren

PH-517-06

MECHANICAL OPTICAL LABORATORY

Servicereq.	F050	Applicant:	H.Weeber	Dept: AR	Code: 570	Date: [redacted]
Project:	5.13	Descr:	Bifocal Foldable			
Item:		Descr:	SA Nummer pilot plant SA020560 (van blz.A t/m H)			
Series:	Nr_1	No.of samples: 24	/type/ diopter/? BF//15.0/20.0/26.0D	Remarks:	Measured by: MO-Laboratory	
Descr:	Lenstype K1 // gemeten met 3mm aperture					

total 8 .	OPTICAL BENCH																			
	ISO-EYE MODEL WITH Z9000 CORNEA																			
	15.0 D						20.0 D						26.0 D							
	FAR			NEAR			FAR			NEAR			FAR			NEAR				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	[c/mm]																			
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.33	0.25	0.17	0.35	0.27	0.22	0.34	0.27	0.19	0.35	0.27	0.21	0.37	0.30	0.22	0.38	0.29	0.20		
2	0.37	0.30	0.22	0.36	0.29	0.23	0.34	0.26	0.22	0.33	0.26	0.20	0.36	0.28	0.21	0.40	0.30	0.23		
3	0.36	0.29	0.19	0.36	0.29	0.23	0.33	0.25	0.17	0.34	0.25	0.20	0.37	0.30	0.21	0.38	0.31	0.22		
4	0.37	0.30	0.21	0.35	0.29	0.22	0.34	0.28	0.19	0.34	0.27	0.19	0.38	0.31	0.23	0.39	0.32	0.25		
5	0.37	0.29	0.21	0.35	0.30	0.23	0.35	0.28	0.19	0.33	0.28	0.21	0.38	0.30	0.23	0.39	0.32	0.24		
6	0.35	0.29	0.17	0.35	0.28	0.21	0.34	0.30	0.22	0.35	0.28	0.23	0.38	0.30	0.22	0.37	0.30	0.22		
7	0.35	0.29	0.19	0.35	0.27	0.19	0.34	0.30	0.20	0.35	0.28	0.21	0.37	0.31	0.23	0.38	0.31	0.24		
8	0.37	0.31	0.22	0.34	0.28	0.22	0.34	0.27	0.20	0.34	0.28	0.21	0.35	0.29	0.21	0.39	0.31	0.24		
avg	0.36	0.29	0.20	0.35	0.28	0.22	0.34	0.28	0.20	0.34	0.27	0.21	0.37	0.30	0.22	0.39	0.31	0.23		
std	0.015	0.018	0.021	0.006	0.011	0.014	0.005	0.018	0.017	0.008	0.011	0.012	0.010	0.010	0.009	0.009	0.010	0.016		
min	0.33	0.25	0.17	0.34	0.27	0.19	0.33	0.25	0.17	0.33	0.25	0.19	0.35	0.28	0.21	0.37	0.29	0.20		
max	0.37	0.31	0.22	0.36	0.30	0.23	0.35	0.30	0.22	0.35	0.28	0.23	0.38	0.31	0.23	0.40	0.32	0.25		

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MECHANICAL OPTICAL LABORATORY

Servicereq.	F050	Applicant:	H.Weeber	Dept: AR	Code: 570	Date: [redacted]
Project:	5.13	Descr:	Bifocal Foldable			
Item:		Descr:	SA Nummer pilot plant SA020560 (van blz.A t/m H)			
Series:	Nr_2	No.of samples: 24	/type/ diopter/? BF//15.0/20.0/26.0D	Remarks:	Measured by: MO-Laboratory	
Descr:	Lenstype K1 Z9000 // gemeten met 3mm aperture					

total 8	OPTICAL BENCH																			
	ISO-EYE MODEL WITH Z9000 CORNEA																			
	15.0 D						20.0 D						26.0 D							
	FAR			NEAR			FAR			NEAR			FAR			NEAR				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	[c/mm]																			
date						[redacted]									[redacted]					
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.38	0.34	0.23	0.35	0.30	0.24	0.35	0.26	0.14	0.34	0.24	0.15	0.40	0.31	0.22	0.35	0.28	0.20		
2	0.37	0.30	0.20	0.34	0.26	0.20	0.38	0.29	0.20	0.36	0.30	0.22	0.37	0.28	0.18	0.37	0.30	0.22		
3	0.37	0.30	0.18	0.35	0.26	0.18	0.38	0.32	0.23	0.37	0.30	0.25	0.39	0.32	0.23	0.37	0.30	0.22		
4	0.36	0.31	0.21	0.36	0.30	0.24	0.40	0.31	0.22	0.36	0.30	0.21	0.39	0.33	0.25	0.36	0.31	0.25		
5	0.37	0.29	0.19	0.34	0.28	0.22	0.40	0.32	0.20	0.36	0.28	0.21	0.36	0.28	0.17	0.36	0.27	0.17		
6	0.37	0.30	0.17	0.35	0.28	0.22	0.40	0.32	0.24	0.37	0.32	0.25	0.38	0.29	0.19	0.37	0.30	0.21		
7	0.38	0.31	0.22	0.35	0.29	0.22	0.39	0.32	0.21	0.36	0.28	0.21	0.38	0.31	0.21	0.35	0.28	0.19		
8	0.37	0.30	0.21	0.34	0.28	0.22	0.38	0.29	0.18	0.36	0.30	0.24	0.38	0.31	0.21	0.38	0.30	0.22		
avg	0.37	0.31	0.20	0.35	0.28	0.22	0.39	0.30	0.20	0.36	0.29	0.22	0.38	0.30	0.21	0.36	0.29	0.21		
std	0.008	0.015	0.020	0.007	0.016	0.020	0.017	0.022	0.032	0.009	0.024	0.032	0.012	0.018	0.027	0.011	0.014	0.024		
min	0.36	0.29	0.17	0.34	0.26	0.18	0.35	0.26	0.14	0.34	0.24	0.15	0.36	0.28	0.17	0.35	0.27	0.17		
max	0.38	0.34	0.23	0.36	0.30	0.24	0.40	0.32	0.24	0.37	0.32	0.25	0.40	0.33	0.25	0.38	0.31	0.25		

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MECHANICAL OPTICAL LABORATORY

Servicereq.	F050	Applicant:	H.Weeber			Dept: AR					Code: 570			Date: [redacted]					
Project:	5.13	Descr:	Bifocal Foldable																
Item:		Descr:	SA Nummer pilot plant SA020560 (van blz.A t/m H)																
Series:	Nr_1_15D	No.of samples: 24		/type/ diopter/? BF//15.0D						Remarks:		Measured by: MO-Laboratory							
Descr:	Lenstype K1 gemeten met 5mm aperture																		
total 8	OPTICAL BENCH																		
	ISO-EYE MODEL WITH Z9000 CORNEA																		
	FAR									NEAR									
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees			
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	
unit	[c/mm]																		
date	[redacted]																		
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19 / 20
1	0.40	0.35	0.27	0.40	0.33	0.23	0.42	0.34	0.23	0.31	0.27	0.18	0.33	0.25	0.14	0.31	0.28	0.21	
2	0.40	0.32	0.21	0.42	0.30	0.17	0.43	0.32	0.23	0.31	0.23	0.12	0.29	0.21	0.10	0.33	0.28	0.20	
3	0.41	0.33	0.23	0.41	0.31	0.19	0.43	0.34	0.23	0.32	0.27	0.18	0.29	0.22	0.10	0.32	0.28	0.21	
4	0.42	0.34	0.23	0.42	0.33	0.23	0.42	0.33	0.24	0.32	0.26	0.16	0.33	0.25	0.13	0.34	0.28	0.20	
5	0.41	0.32	0.20	0.38	0.27	0.15	0.39	0.30	0.21	0.30	0.24	0.13	0.28	0.20	0.09	0.30	0.25	0.18	
6	0.40	0.32	0.22	0.40	0.30	0.18	0.43	0.34	0.25	0.30	0.25	0.15	0.31	0.23	0.12	0.32	0.27	0.20	
7	0.40	0.31	0.19	0.40	0.34	0.26	0.42	0.33	0.23	0.29	0.23	0.12	0.32	0.24	0.14	0.31	0.27	0.19	
8	0.40	0.32	0.23	0.43	0.34	0.26	0.40	0.32	0.23	0.32	0.26	0.18	0.30	0.26	0.18	0.33	0.28	0.22	
avg	0.41	0.33	0.22	0.41	0.32	0.21	0.42	0.33	0.23	0.31	0.25	0.15	0.31	0.23	0.13	0.32	0.27	0.20	
std	0.008	0.013	0.024	0.016	0.024	0.042	0.015	0.014	0.011	0.011	0.018	0.027	0.019	0.021	0.029	0.013	0.011	0.012	
min	0.40	0.31	0.19	0.38	0.27	0.15	0.39	0.30	0.21	0.29	0.23	0.12	0.28	0.20	0.09	0.30	0.25	0.18	
max	0.42	0.35	0.27	0.43	0.34	0.26	0.43	0.34	0.25	0.32	0.27	0.18	0.33	0.28	0.18	0.34	0.28	0.22	
gr.avg			0.41		0.32		0.22					0.31		0.25		0.16			
gr.std			0.014		0.018		0.029					0.016		0.023		0.040			
gr.min			0.38		0.27		0.15					0.28		0.20		0.09			
gr.max			0.43		0.35		0.27					0.34		0.28		0.22			
gr.cols.			(1 4 7)		(2 5 8)		(3 6 9)					(10 13 16)		(11 14 17)		(12 15 18)			

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page C_:1 of 1

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MECHANICAL OPTICAL LABORATORY

Servicereq.: F050 Applicant: H.Weeber Dept: AR Code: 570 Date: [redacted]
Project: 5.13 Descr: Bifocal Foldable
Item: Descr: SA Nummer pilot plant SA020560 (van blz.A t/m H)
Series: Nr_1_20D No.of samples: 8 /type/ diopter/? BF//20.0 D Remarks: Measured by: MO-Laboratory
Descr: Lenstype K1 // gemeten met 5mm aperture

OPTICAL BENCH — ISO-EYE MODEL WITH Z9000 CORNEA (total 8; unit [c/mm]; date [redacted])

	FAR									NEAR										
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.37	0.28	0.15	0.38	0.24	0.12	0.39	0.28	0.17	0.30	0.22	0.13	0.30	0.21	0.11	0.31	0.26	0.19		
2	0.37	0.28	0.15	0.40	0.29	0.18	0.38	0.27	0.16	0.32	0.27	0.19	0.30	0.26	0.16	0.30	0.26	0.18		
3	0.39	0.32	0.19	0.41	0.33	0.20	0.39	0.30	0.19	0.31	0.28	0.21	0.32	0.27	0.18	0.30	0.25	0.19		
4	0.42	0.36	0.25	0.42	0.35	0.24	0.43	0.35	0.25	0.33	0.29	0.21	0.33	0.29	0.20	0.32	0.30	0.23		
5	0.41	0.33	0.24	0.42	0.33	0.20	0.41	0.32	0.21	0.32	0.28	0.20	0.31	0.28	0.18	0.33	0.30	0.23		
6	0.41	0.33	0.23	0.42	0.33	0.23	0.43	0.35	0.25	0.33	0.28	0.22	0.31	0.29	0.21	0.32	0.28	0.23		
7	0.42	0.35	0.25	0.41	0.35	0.24	0.42	0.33	0.21	0.33	0.29	0.20	0.32	0.27	0.18	0.30	0.27	0.17		
8	0.41	0.33	0.23	0.42	0.35	0.24	0.42	0.31	0.17	0.32	0.29	0.22	0.33	0.29	0.21	0.31	0.28	0.19		
avg	0.40	0.32	0.21	0.41	0.32	0.21	0.41	0.31	0.20	0.32	0.28	0.20	0.32	0.27	0.18	0.31	0.28	0.20		
std	0.021	0.029	0.042	0.014	0.038	0.042	0.020	0.030	0.035	0.011	0.023	0.029	0.012	0.027	0.033	0.011	0.019	0.025		
min	0.37	0.28	0.15	0.38	0.24	0.12	0.38	0.27	0.16	0.30	0.22	0.13	0.30	0.21	0.11	0.30	0.25	0.17		
max	0.42	0.36	0.25	0.42	0.35	0.24	0.43	0.35	0.25	0.33	0.29	0.22	0.33	0.29	0.21	0.33	0.30	0.23		

gr.avg	0.41	0.32	0.21	0.32	0.27	0.19
gr.std	0.018	0.031	0.038	0.011	0.022	0.030
gr.min	0.37	0.24	0.12	0.30	0.21	0.11
gr.max	0.43	0.36	0.25	0.33	0.30	0.23
gr.cols.	(1 4 7)	(2 5 8)	(3 6 9)	(10 13 16)	(11 14 17)	(12 15 18)

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MECHANICAL OPTICAL LABORATORY

Servicereq.	F050	Applicant:	H.Weeber	Dept: AR	Code: 570	Date: [redacted]
Project:	5.13	Descr:	Bifocal Foldable			
Item:		Descr:	SA Nummer pilot plant SA020560 (van blz.A t/m H)			
Series:	Nr_1_26D	No.of samples: 24	/type/ diopter/? BF// 26.0D		Remarks:	Measured by: MO-Laboratory
Descr:	Lenstype K1 // gemeten met 5mm aperture					

total 8	OPTICAL BENCH																			
	ISO-EYE MODEL WITH Z9000 CORNEA																			
	FAR									NEAR										
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	[c/mm]																			
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.42	0.34	0.23	0.41	0.38	0.21	0.41	0.33	0.22	0.30	0.27	0.18	0.31	0.25	0.15	0.31	0.28	0.20		
2	0.39	0.29	0.18	0.37	0.27	0.16	0.38	0.29	0.20	0.30	0.23	0.13	0.30	0.20	0.09	0.29	0.26	0.19		
3	0.40	0.29	0.17	0.41	0.33	0.22	0.38	0.29	0.19	0.29	0.25	0.15	0.31	0.25	0.17	0.29	0.24	0.16		
4	0.41	0.32	0.21	0.39	0.29	0.16	0.40	0.34	0.24	0.31	0.24	0.15	0.29	0.22	0.10	0.31	0.29	0.21		
5	0.42	0.33	0.22	0.41	0.30	0.18	0.42	0.34	0.23	0.30	0.24	0.15	0.28	0.19	0.10	0.30	0.28	0.20		
6	0.43	0.35	0.24	0.41	0.34	0.24	0.40	0.31	0.19	0.30	0.26	0.16	0.31	0.25	0.16	0.30	0.26	0.18		
7	0.41	0.31	0.20	0.40	0.32	0.22	0.40	0.30	0.18	0.31	0.26	0.16	0.31	0.26	0.17	0.30	0.24	0.15		
8	0.41	0.31	0.19	0.42	0.35	0.24	0.40	0.31	0.19	0.31	0.28	0.20	0.30	0.26	0.18	0.31	0.26	0.19		
avg	0.41	0.32	0.21	0.40	0.32	0.20	0.40	0.31	0.21	0.30	0.25	0.16	0.30	0.24	0.14	0.30	0.26	0.19		
std	0.012	0.022	0.024	0.018	0.035	0.033	0.014	0.021	0.022	0.007	0.017	0.021	0.011	0.028	0.037	0.008	0.018	0.021		
min	0.39	0.29	0.17	0.37	0.27	0.16	0.38	0.29	0.18	0.29	0.23	0.13	0.28	0.19	0.09	0.29	0.24	0.15		
max	0.43	0.35	0.24	0.42	0.38	0.24	0.42	0.34	0.24	0.31	0.28	0.20	0.31	0.26	0.18	0.31	0.29	0.21		
gr.avg			0.40		0.32			0.20				0.30		0.25		0.16				
gr.std			0.014		0.026			0.026				0.009		0.024		0.032				
gr.min			0.37		0.27			0.16				0.28		0.19		0.09				
gr.max			0.43		0.38			0.24				0.31		0.29		0.21				
gr.cols.			(1 4 7)		(2 5 8)			(3 6 9)				(10 13 16)		(11 14 17)		(12 15 18)				

[redacted]

page E_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq. F050	Applicant: H.Weeber	Dept: AR	Code: 570	Date: [redacted]		
Project: 5.13	Descr: Bifocal Foldable					
Item:	Descr: SA Nummer pilot plant SA020560 (van blz.A t/m H)					
Series: Nr_2_15D	No.of samples: 24	/type/ diopter/? BF// 15.0D	Remarks:	Measured by: MO-Laboratory		
Descr: Lenstype Z8000 // gemeten met 5mm aperture						

total 8	OPTICAL BENCH																			
	ISO-EYE MODEL WITH Z8000 CORNEA																			
	FAR									NEAR										
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	[c/mm]																			
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.39	0.30	0.18	0.39	0.31	0.20	0.41	0.32	0.20	0.32	0.27	0.18	0.31	0.27	0.19	0.31	0.28	0.22		
2	0.39	0.31	0.18	0.41	0.33	0.22	0.42	0.31	0.16	0.32	0.27	0.17	0.33	0.29	0.23	0.32	0.27	0.18		
3	0.40	0.33	0.21	0.40	0.32	0.22	0.41	0.31	0.16	0.32	0.27	0.21	0.32	0.29	0.22	0.32	0.27	0.20		
4	0.40	0.32	0.19	0.42	0.36	0.25	0.43	0.35	0.25	0.32	0.29	0.24	0.33	0.28	0.19	0.33	0.28	0.21		
5	0.40	0.32	0.22	0.42	0.35	0.23	0.41	0.31	0.19	0.31	0.27	0.18	0.33	0.28	0.20	0.32	0.27	0.20		
6	0.41	0.33	0.20	0.41	0.35	0.25	0.40	0.29	0.13	0.32	0.27	0.18	0.33	0.27	0.20	0.32	0.25	0.15		
7	0.41	0.31	0.17	0.42	0.33	0.23	0.42	0.32	0.19	0.31	0.27	0.19	0.31	0.25	0.16	0.32	0.27	0.19		
8	0.41	0.33	0.18	0.43	0.34	0.22	0.42	0.34	0.22	0.32	0.26	0.16	0.33	0.27	0.17	0.34	0.29	0.21		
avg	0.40	0.32	0.19	0.41	0.34	0.23	0.42	0.32	0.19	0.32	0.27	0.19	0.32	0.28	0.20	0.32	0.27	0.19		
std	0.008	0.011	0.017	0.013	0.017	0.017	0.009	0.019	0.038	0.005	0.008	0.025	0.009	0.013	0.023	0.009	0.012	0.025		
min	0.39	0.30	0.17	0.39	0.31	0.20	0.40	0.29	0.13	0.31	0.26	0.16	0.31	0.25	0.16	0.31	0.25	0.15		
max	0.41	0.33	0.22	0.43	0.36	0.25	0.43	0.35	0.25	0.32	0.29	0.24	0.33	0.29	0.23	0.34	0.29	0.22		
gr.avg			0.41		0.32		0.20					0.32		0.27		0.19				
gr.std			0.012		0.017		0.031					0.008		0.011		0.024				
gr.min			0.39		0.29		0.13					0.31		0.25		0.15				
gr.max			0.43		0.36		0.25					0.34		0.29		0.24				
gr.cols.			(1 4 7)		(2 5 6)		(3 6 9)					(10 13 16)		(11 14 17)		(12 15 18)				

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page F_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq. F050 Applicant: H.Weeber Dept: AR Code: 570 Date: [redacted]
Project: 5.13 Descr: Bifocal Foldable
Item: Descr: SA Nummer pilot plant SA020560 (van blz.A t/m H)
Series: nr_2_20D No.of samples: 24 /type/ diopter/? BF// 20.0D Remarks: Measured by: MO-Laboratory
Descr: Lenstype Z9000 // gemeten met 5mm aperture

total 8	OPTICAL BENCH																			
	ISO-EYE MODEL WITH Z9000 CORNEA																			
	FAR									NEAR										
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	(c/mm)																			
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.40	0.30	0.19	0.42	0.33	0.23	0.41	0.30	0.18	0.30	0.27	0.20	0.29	0.26	0.21	0.30	0.25	0.18		
2	0.40	0.31	0.18	0.42	0.32	0.20	0.40	0.28	0.15	0.30	0.27	0.18	0.31	0.27	0.17	0.31	0.25	0.15		
3	0.39	0.24	0.11	0.34	0.17	0.07	0.42	0.31	0.17	0.28	0.21	0.12	0.24	0.13	0.07	0.29	0.25	0.16		
4	0.40	0.30	0.16	0.41	0.31	0.17	0.40	0.28	0.14	0.31	0.26	0.17	0.30	0.25	0.15	0.30	0.25	0.16		
5	0.41	0.30	0.18	0.40	0.33	0.21	0.41	0.31	0.18	0.30	0.25	0.15	0.32	0.29	0.22	0.29	0.26	0.17		
6	0.38	0.28	0.17	0.41	0.28	0.14	0.42	0.32	0.21	0.30	0.27	0.18	0.29	0.24	0.14	0.32	0.28	0.23		
7	0.40	0.30	0.17	0.40	0.28	0.15	0.40	0.30	0.18	0.31	0.25	0.18	0.30	0.25	0.14	0.32	0.28	0.21		
8	0.40	0.31	0.19	0.41	0.32	0.21	0.40	0.30	0.18	0.31	0.28	0.19	0.30	0.26	0.18	0.30	0.26	0.18		
avg	0.40	0.29	0.17	0.40	0.29	0.17	0.41	0.30	0.17	0.30	0.26	0.17	0.29	0.24	0.16	0.30	0.28	0.18		
std	0.009	0.023	0.026	0.026	0.053	0.052	0.009	0.014	0.021	0.010	0.022	0.025	0.024	0.048	0.047	0.012	0.013	0.027		
min	0.38	0.24	0.11	0.34	0.17	0.07	0.40	0.28	0.14	0.28	0.21	0.12	0.24	0.13	0.07	0.29	0.25	0.15		
max	0.41	0.31	0.19	0.42	0.33	0.23	0.42	0.32	0.21	0.31	0.28	0.20	0.32	0.29	0.22	0.32	0.28	0.23		
gr.avg			0.40		0.30		0.17					0.30		0.25		0.17				
gr.std			0.016		0.033		0.034					0.016		0.031		0.034				
gr.min			0.34		0.17		0.07					0.24		0.13		0.07				
gr.max			0.42		0.33		0.23					0.32		0.29		0.23				
gr.cols.			(1 4 7)		(2 5 8)		(3 6 9)					(10 13 16)		(11 14 17)		(12 15 18)				

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page G_:1 of 1

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MECHANICAL OPTICAL LABORATORY

Servicereq.: F050 Applicant: H.Weeber Dept: AR Code: 570 Date: [redacted]
Project: 5.13 Descr: Bifocal Foldable
Item: Descr: SA Nummer pilot plant SA020560 (van blz.A t/m H)
Series: Nr_2_26D No.of samples: 24 /type/ diopter/? BF// 26.0D Remarks: Measured by: MO-Laboratory
Descr: Lenstype Z9000 // gemeten met 5mm aperture

total 8 — OPTICAL BENCH — ISO-EYE MODEL WITH Z9000 CORNEA

	FAR									NEAR										
	0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees				
	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100		
unit	[c/mm]																			
date	[redacted]																			
column	1	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20
1	0.40	0.31	0.18	0.40	0.33	0.21	0.38	0.26	0.12	0.31	0.27	0.19	0.32	0.27	0.20	0.29	0.23	0.14		
2	0.40	0.30	0.18	0.41	0.32	0.22	0.39	0.28	0.18	0.30	0.25	0.17	0.31	0.25	0.19	0.29	0.25	0.17		
3	0.40	0.31	0.18	0.41	0.35	0.24	0.38	0.29	0.13	0.31	0.27	0.19	0.31	0.27	0.21	0.30	0.24	0.14		
4	0.39	0.26	0.12	0.39	0.30	0.18	0.40	0.31	0.19	0.30	0.24	0.12	0.30	0.23	0.12	0.31	0.28	0.21		
5	0.40	0.28	0.13	0.40	0.32	0.18	0.38	0.24	0.09	0.30	0.24	0.15	0.32	0.26	0.17	0.30	0.20	0.08		
6	0.40	0.30	0.16	0.40	0.34	0.23	0.40	0.30	0.16	0.30	0.27	0.20	0.31	0.26	0.20	0.30	0.26	0.18		
7	0.39	0.28	0.11	0.42	0.33	0.22	0.39	0.29	0.14	0.31	0.26	0.17	0.30	0.26	0.18	0.30	0.27	0.19		
8	0.40	0.30	0.17	0.39	0.27	0.14	0.41	0.32	0.20	0.30	0.24	0.13	0.29	0.21	0.10	0.29	0.28	0.21		
avg	0.40	0.29	0.15	0.40	0.32	0.20	0.39	0.29	0.15	0.30	0.26	0.17	0.31	0.25	0.17	0.30	0.25	0.17		
std	0.005	0.018	0.029	0.010	0.025	0.033	0.011	0.026	0.038	0.005	0.014	0.029	0.010	0.021	0.040	0.007	0.027	0.044		
min	0.39	0.26	0.11	0.39	0.27	0.14	0.38	0.24	0.09	0.30	0.24	0.12	0.29	0.21	0.10	0.29	0.20	0.08		
max	0.40	0.31	0.18	0.42	0.35	0.24	0.41	0.32	0.20	0.31	0.27	0.20	0.32	0.27	0.21	0.31	0.28	0.21		

gr.avg		0.40	0.30	0.17			0.30	0.25	0.17	
gr.std		0.010	0.027	0.040			0.009	0.021	0.037	
gr.min		0.38	0.24	0.09			0.29	0.20	0.08	
gr.max		0.42	0.35	0.24			0.32	0.28	0.21	
gr.cols.		(1 4 7)	(2 5 8)	(3 6 9)			(10 13 16)	(11 14 17)	(12 15 18)	

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page H_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq. F050 Applicant: H.Weeber Dept: AR Code: 570 Date: [redacted]
Project: 5.13 Descr: Bifocal Foldable
Item: Descr: SA Nummer pilot plant SA020560 (van biz.A t/m H)
Series: Nr_3 No.of samples: 3 /type/ diopter/? 811E//15.0/20.0/25.0 Remarks: Measured by: MO-Laboratory
Descr: Lenstype 811E // gemeten met 3mm aperture

total	OPTICAL BENCH																			
3	ISO-EYE MODEL WITH Z9000 CORNEA																			
	POWER	FAR			NEAR															
		25	50	100	25	50	100													
unit		[c/mm]																		
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	15.0 D	0.37	0.30	0.24	0.35	0.28	0.22													
2	20.0 D	0.33	0.25	0.16	0.38	0.30	0.24													
3	25.0D	0.36	0.31	0.22	0.39	0.27	0.17													

[redacted] page I_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq.: F050 Applicant: H.Weeber Dept: AR Code: 570 Date: [redacted]
Project: 5.13 Descr: Bifocal Foldable
Item: Descr: SA Nummer pilot plant SA020560 (van blz.A t/m H)
Series: Nr_3 No.of samples: 3 /type/ diopter/? 811E//15.0/20.0/25.0 Remarks: Measured by: MO-Laboratory
Descr: Lenstype 811E // gemeten met 5mm aperture

total	OPTICAL BENCH																			
ERR	ISO-EYE MODEL WITH Z9000 CORNEA																			
	POWER	FAR									NEAR									
		0 degrees			-45 degrees			+45 degrees			0 degrees			-45 degrees			+45 degrees			
		25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	25	50	100	
unit		[c/mm]																		
date		[redacted]																		
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	15.0 D	0.20	0.09	0.01	0.20	0.10	0.02	0.19	0.10	0.02	0.23	0.07	0.01	0.22	0.08	0.01	0.23	0.08	0.00	
2	20.0 D	0.20	0.10	0.02	0.19	0.09	0.02	0.19	0.09	0.02	0.22	0.07	0.04	0.23	0.09	0.02	0.22	0.08	0.02	
3	25.0 D	0.18	0.06	0.04	0.18	0.07	0.03	0.18	0.07	0.02	0.16	0.03	0.03	0.14	0.02	0.03	0.15	0.03	0.02	

[redacted] page J_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq.	F050	Applicant:	H.Weeber	Dept:	AR	Code:	570	Date:	[redacted]
Project:	5.13	Descr:	Bifocal Foldable						
Item:		Descr:	SA Nummer pilot plant SA020560 (van blz.A t/m H)						

	METINGEN	Spec.Doc.	WVS
LENZEN	MTF:	geen	geen

VERBRUIKTE LENZEN

BIFOCAL FOLDABLE			
SERVICE NR	MODEL	DIOPTER	Gemeten Nummers
SA 020560 K1	513BF	15.0D	2/5 en 7/10
SA 020560 K1	513BF	20.0D	1/8
SA 020560 K1	513BF	26.0D	1/8
SA 020560 K1Z900	513BF	15.0D	1/8
SA 020560 K1Z900	513BF	20.0D	1/8
SA 020560 K1Z900	513BF	26.0D	1/8

811E		
Batch nr.	Lens nr.	Power
4224 06	01 9	15.0 D
4225 21	01 7	20.0D
4207 22	11 2	25.0 D

ALGEMEEN:

De MTF metingen zijn gedaan met: ISO houder en Z9000 cornea
Objectief 20.8X
lenshouder 3-en 5mm

Gullstrand houder met Z9000 cornea
Objectief 39.3X
lensinserts 3- en 5mm
NVT [redacted]

Vloeistof is speciaal aangemaakt: millipure met PEG (Brekingsindex: 1.3406 ± 0,0002)

MEETPROGRAMM Hetzelfde als bij MTF metingen
De window was handmatig ingesteld
Hij is bij het array signal op het midden van de laatste 2 blokjes afgesteld

DE METINGEN Er is alleen bij 25 c/mm gefocuseerd
De getallen bij 50 en 100c/mm komen van het focuspunt 25c/mm

[redacted] page Comments Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Pharmacia &Upjohn

		AANVRAAGNR.:	F054
AANVRAGER:	H.Weeber	AANVRAAGDATUM:	[redacted]
AFDELING:	AR	AFD.CODE:	
PROJECT/OMSCHRIJVING:	5.13 Bifocal Foldable		

TYPE LENS: Prototype bifocal foldable

M-/BATCHNUMMER	DIOPTRIE	AANTAL
SA 020560 Z9000 K1	15.0D	8
SA 020560 Z9000 K1	20.0D	8
SA 020560 Z9000 K1	26.0D	8

GEWENSTE METINGEN

MASSA	
OVERALL DIAMETER	
OPTIEK DIAMETER	
BREEDTE-/DIAMETER VAN DE LUSSEN	
DIKTE VAN DE LUSSEN	
STAND VAN DE LUSSEN/STEP HEIGHT	
EDGE THICKNESS	
COMPRESSION FORCE	
AXIAL DISPLACEMENT IN COMPRESSION	
TILT	
AXIAL RIGIDITY	
AMOUNT OF TOUCH	
DECENTRATION	

MTF/EFL	
BACK FOCAL LENGTH	X
DIOPTRIE	
RESOLUTIE	
BURSTTEST	
TREKSTERKTE	

AFWIJKENDE METINGEN

OPMERKINGEN	Meting in de watebak
	apertuur 3 mm
	Brekingsindex van het water = 1.3406 ±0,0002

MECHANICAL OPTICAL LABORATORY

Servicereq. F054 Applicant: H.Weeber Dept: AR Code: Date: [redacted]
Project: 5.13 Descr: Multifocal foldable lens // Prototype K1-Z9000
Item: Descr:
Series: SERIE_1A No.of samples: 4 /type/ diopter/? K1-Z9000//15.0D Remarks: Measured by:MO laboratory
Descr:

total ERR: EROS OPTICAL BENCH — WATERBATH // WITH FIXTURE APERTURE =3mm

	Lens-1					Lens-2					lens-3					Lens-4				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date	[redacted]																			
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	75.086		95.767			75.125		96.837			76.109		98.695			76.000		96.752		
2	74.203	0.02	94.616	0.06		74.221	0.16	95.706	0.19		75.251	0.01	95.597	0.06		74.651	0.07	95.750	0.06	
3	73.400	0.10	93.505	0.18		73.333	0.24	94.635	0.26		74.302	0.16	94.498	0.15		74.200	0.15	94.750	0.17	
4	72.602	0.29	92.404	0.17		72.441	0.41	93.525	0.27		73.356	0.35	93.395	0.20		73.853	0.22	93.750	0.20	
5	71.801	0.27	91.302	0.08		71.553	0.27	92.400	0.19		72.408	0.21	92.296	0.11		73.300	0.33	92.750	0.15	
6	71.003	0.14	90.201	0.07		70.661	0.16	91.306	0.14		71.451	0.15	91.194	0.07		72.850	0.28	91.750	0.10	
7	70.199	0.02	89.104	0.03		69.774	0.09	90.215	0.08		70.502	0.01	90.166			72.200	0.17	90.803		
8	69.402		88.874			69.199		89.934			70.407					71.750	0.09			

[redacted]

page A_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq.	F054	Applicant:	H.Weeber	Dept: AR		Code:	Date: [redacted]
Project:	5.13	Descr:	Multifocal foldable lens // Prototype K1-Z9000				
Item:		Descr:					
Series:	SERIE_1B	No.of samples: 4	/type/ diopter/?	K1-Z9000//15.0D	Remarks:	Measured by:MO laboratory	
Descr:							

total	EROS OPTICAL BENCH																			
ERR	WATERBATH // WITH FIXTURE APERTURE =3mm																			
	Lens-5					Lens-6					lens-7					Lens-8				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date									[redacted]											
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	70.589		90.584			69.413		89.000			70.239		89.675			69.860		90.079		
2	71.512	0.06	91.406	0.04		70.408	0.02	90.111	0.04		71.034	0.10	90.592	0.08		70.756	0.04	90.908	0.07	
3	72.415	0.19	92.217	0.08		71.410	0.19	91.205	0.09		71.438	0.15	91.576	0.12		71.311	0.13	91.809	0.11	
4	73.318	0.27	93.015	0.06		71.908	0.26	92.308	0.13		71.834	0.20	92.494	0.14		71.805	0.26	92.705	0.17	
5	74.201	0.10	93.418	0.13		72.411	0.24	92.903	0.15		72.235	0.30	93.016	0.19		72.304	0.28	93.153	0.18	
6	74.505	0.04	93.813	0.14		72.200	0.28	93.506	0.12		72.635	0.22	93.496	0.14		72.803	0.23	93.607	0.16	
7	75.970		94.231	0.14		72.908	0.19	94.600	0.04		73.035	0.15	94.304	0.07		73.148	0.18	94.502	0.06	
8			95.008	0.04		73.404	0.11	95.925			73.436	0.08	95.390			73.603	0.06	95.322		
9			96.448			75.296					75.027					75.234				

[redacted] page B_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq. F054 Applicant: H.Weeber Dept: AR Code: Date: [redacted]
Project: 5.13 Descr: Multifocal foldable lens // Prototype K1-Z9000
Item: Descr:
Series: SERIE_2A No.of samples: 4 /type/ diopter/? K1-Z9000//20.0D Remarks: Measured by:MO laboratory
Descr:

total	EROS OPTICAL BENCH																			
ERR	WATERBATH // WITH FIXTURE APERTURE =3mm																			
	Lens-1					Lens-2					lens-3					Lens-4				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date										[redacted]										
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	53.598		64.708			53.362		70.839			60.876		66.163			53.510		70.910		
2	54.592	0.01	65.803	0.05		54.456	0.01	69.803	0.02		59.622	0.03	67.112	0.03		54.510	0.02	65.304	0.05	
3	55.597	0.13	66.904	0.08		55.561	0.11	68.803	0.14		58.360	0.06	68.112	0.07		55.509	0.11	66.405	0.06	
4	56.097	0.22	67.504	0.11		55.824	0.16	68.301	0.17		57.154	0.16	68.612	0.12		56.008	0.24	67.504	0.13	
5	56.595	0.24	68.052	0.14		56.106	0.21	67.805	0.16		56.553	0.29	69.110	0.18		56.323	0.32	68.107	0.20	
6	57.092	0.12	68.602	0.16		56.401	0.26	67.207	0.08		55.952	0.20	69.613	0.15		56.609	0.30	68.657	0.20	
7	57.592	0.05	69.153	0.09		56.701	0.28	64.705			55.349	0.08	70.109	0.12		57.110	0.15	69.204	0.14	
8	58.596	0.03	69.703	0.03		57.004	0.17				53.326		70.607	0.05		58.108	0.03	69.753	0.04	
9	59.864		71.248			57.310	0.11						72.137			59.629		64.207		
10						59.873														

[redacted] page C_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq.	F054	Applicant:	H.Weeber	Dept:	AR	Code:		Date:	[redacted]
Project:	5.13	Descr:	Multifocal foldable lens // Prototype K1-Z9000						
Item:		Descr:							
Series:	SERIE_28	No.of samples:	4	/type/ diopter/?	K1-Z9000	Remarks:	Measured by:MO laboratory		
Descr:									

total ERR	EROS OPTICAL BENCH — WATERBATH // WITH FIXTURE APERTURE =3mm																			
	Lens-5					Lens-6					lens-7					Lens-8				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date									[redacted]											
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	53.639		65.021			54.129		65.151			54.049		65.451			53.916		65.312		
2	54.625	0.04	66.053	0.03		55.078	0.05	66.655	0.04		55.502	0.11	66.358	0.05		55.415	0.09	66.313	0.04	
3	55.633	0.12	67.503	0.09		55.576	0.10	67.654	0.11		56.006	0.25	67.255	0.10		55.916	0.19	67.314	0.08	
4	56.335	0.28	68.004	0.16		56.027	0.18	68.153	0.15		56.506	0.32	68.154	0.20		56.416	0.31	67.813	0.14	
5	57.130	0.17	68.504	0.17		56.476	0.24	68.651	0.19		57.005	0.22	68.603	0.21		56.914	0.20	68.314	0.17	
6	57.626	0.06	69.004	0.14		57.026	0.23	69.154	0.14		57.507	0.11	69.053	0.20		57.415	0.07	68.813	0.16	
7	59.866		69.504	0.08		57.475	0.12	69.652	0.05		59.321		69.503	0.050		59.867		69.315	0.08	
8			71.004			58.027	0.05	71.147					70.801					71.228		
9						59.820														

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MECHANICAL OPTICAL LABORATORY

Servicereq.	F054	Applicant:	H Weeber	Dept:	AR	Code:		Date:	[redacted]
Project:	5.13	Descr:	Multifocal foldable lens // Prototype K1-Z9000						
Item:		Descr:							
Series:	SERIE_3A	No.of samples:	4	/type/ diopter/?	K1-Z9000/26.0D	Remarks:	Measured by:MO laboratory		
Descr:									

total ERR	EROS OPTICAL BENCH																			
	WATERBATH // WITH FIXTURE APERTURE =3mm																			
	Lens-1					Lens-2					lens-3					Lens-5				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date									[redacted]											
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	47.214		48.617			45.665		49.015			47.179		49.469			48.038		48.286		
2	45.804	0.04	50.615	0.05		45.415	0.13	50.764	0.07		45.674	0.01	50.309	0.04		47.057	0.06	50.789	0.07	
3	45.403	0.08	51.117	0.12		45.165	0.18	51.265	0.13		45.424	0.05	50.752	0.07		46.041	0.04	51.287	0.17	
4	45.003	0.25	51.816	0.19		44.916	0.29	51.766	0.22		45.173	0.14	51.218	0.14		45.276	0.18	51.787	0.27	
5	44.605	0.35	52.112	0.21		44.662	0.32	52.265	0.19		44.924	0.25	51.653	0.23		45.022	0.26	52.288	0.20	
6	44.205	0.23	52.617	0.10		44.415	0.28	52.765	0.08		44.673	0.33	52.106	0.21		44.772	0.37	52.788	0.12	
7	43.805	0.09	53.118	0.03		44.163	0.19	54.547			44.425	0.31	52.335	0.15		44.522	0.33	53.286	0.08	
8	43.405	0.08	54.485			43.912	0.11				44.175	0.22	52.556	0.09		44.270	0.27	54.330		
9	41.813					41.644					43.922	0.11	54.934			44.023	0.140			
10											41.164					43.772	0.050			
11																42.229				

[redacted] page E_:1 of 1 Sign. [redacted] Check: [redacted]

MECHANICAL OPTICAL LABORATORY

Servicereq. F054 Applicant: H.Weeber Dept: AR Code: Date: [redacted]

Project: 5.13 Descr: Multifocal foldable lens // Prototype K1-Z9000

Item: Descr:

Series: SERIE3B No.of samples: 4 /type/ diopter/? 1K-Z9000//26.0D Remarks: Measured by:MO laboratory

Descr:

total	EROS OPTICAL BENCH																			
ERR	WATERBATH // WITH FIXTURE APERTURE =3mm																			
	Lens-6					Lens-7					lens-8					Lens-9				
	NEAR		FAR			NEAR		FAR			NEAR		FAR			NEAR		FAR		
	BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF		BFL	MTF	BFL	MTF	
unit	50c/mm					50c/mm					50c/mm					50c/mm				
date									[redacted]											
column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	48.081		48.696			47.988		49.287			46.981		49.361			46.922		48.252		
2	45.454	0.09	50.697	0.05		45.600	0.08	50.288	0.04		45.483	0.10	50.862	0.06		45.673	0.05	50.754	0.07	
3	45.055	0.27	51.192	0.12		45.454	0.11	50.782	0.06		45.235	0.18	51.362	0.14		45.424	0.15	51.254	0.16	
4	44.543	0.31	51.695	0.23		45.203	0.21	51.286	0.16		44.982	0.34	51.613	0.19		45.172	0.27	51.753	0.27	
5	44.025	0.14	52.195	0.23		44.952	0.34	51.784	0.27		44.732	0.39	51.862	0.27		44.984	0.37	52.003	0.28	
6	43.532	0.09	52.694	0.11		44.702	0.32	52.035	0.31		44.482	0.32	52.112	0.25		44.734	0.33	52.254	0.26	
7	43.031	0.08	54.606			44.454	0.23	52.284	0.27		44.232	0.22	52.362	0.22		44.481	0.27	52.754	0.13	
8	42.452					44.202	0.20	52.534	0.16		43.982	0.13	52.612	0.18		44.233	0.18	53.254	0.080	
9						43.953	0.12	52.784	0.09		43.730	0.07	52.863	0.06		44.983	0.12	54.755		
10						41.930		54.787			42.853		54.234			42.421				

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MECHANICAL OPTICAL LABORATORY

Servicereq. F054	Applicant: H.Weeber	Dept: AR	Code:	Date: 30-05-2002
Project: 5.13	Descr: Multifocal foldable lens // Prototype K1-Z9000			
Item:	Descr:			

Verbruikte Lenzen:

Position	SA numb	Power	Lens nr.
1	SA02056	15.0D	1
2	SA02056	15.0D	2
3	SA02056	15.0D	3
4	SA02056	15.0D	4
5	SA02056	15.0D	5
6	SA02056	15.0D	6
7	SA02056	15.0D	7
8	SA02056	15.0D	8

SA numb	Power	Lens nr.
SA02056	20.0D	1
SA02056	20.0D	2
SA02056	20.0D	3
SA02056	20.0D	4
SA02056	20.0D	5
SA02056	20.0D	6
SA02056	20.0D	7
SA02056	20.0D	8

SA numb	Power	Lens nr.
SA02056	26.0D	1
SA02056	26.0D	2
SA02056	26.0D	3
SA02056	26.0D	5
SA02056	26.0D	6
SA02056	26.0D	7
SA02056	26.0D	8
SA02056	26.0D	9

Algemeen:

De Back Focal Length is als volgt gemeten.

BENODIGDHEDEN: Waterbak voor BFL
10X objectief
Lenshouder (dezelfde als voor de ISO metingen 3mm)

MEETPROGRAMM Hetzelfde als bij MTF metingen
De window was handmatig ingesteld
Hij is bij het array signal op het midden van de laatste 2 blokjes afgesteld

WATERBAK Brekingsindex: 1.3406 ± 0,0002
De vloeistof is apart voor deze lenzen aangemaakt.
Millipure + PEG

Verdere afstellingen van de opstelling als normaal

BFL meting:
De meting is niet op één plaats uitgevoerd maar op meerdere plaatsen
dit is als volgt gedaan:
Op het opp. van de lens is de lengteunit genuld.
Daarna de waterbak zover verplaatst dat er net een MTF waarde zichtbaar werd
Deze verplaatsing is genoteerd
Daarna in verschillende stappen door het best focus heen totdat er geen MTF meer te zien was.
Genoteerd wordt: de stapgrootte en de MTF waarde
Door H. Weeber is hier een best BFL uit berekend.

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Appendix 8. CD rom: data files
(on file in at Documentation Control)